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NITROGEN SUPERSATURATION IN THE COLUMBIA AND SNAKE RIVERS

ENVIRONMENTAL
PROTECTION
AGENCY
REGION X

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16. Abstract Nitrogen supersaturation, caused by the series of hydroelectric dams on the Columbia and Snake Rivers, seriously threatens the future of salmon and steelhead in the Pacific Northwest. A study was made to determine the scope of the problem and recommend solutions. Nitrogen supersaturation is caused when river flows exceed the capacity of power generating turbines in dams and excess flow must be passed over the spillway. The plunge of water into the stilling basin forces excessive air (79 percent nitrogen) into solution. Concentrations of dissolved nitrogen up to 147 percent of surface equilibrium concentrations have been measured. Levels above 105 percent produce symptoms of gas-bubble disease in fish and levels above 120 percent are lethal. Planned installation of slotted gates and bypass of water through empty turbine bays in some dams will reduce spilling but hazardous nitrogen levels will still occur in years of average and higher spring runoff. Increasing use of the hydroelectric system for peak power generation may add to the problem. Recommendations include establishment of a water quality standard of a maximum of 110 percent nitrogen supersaturation, establishment of a regional council to implement a control plan, expanded trapping and hauling of fish around river reaches with high nitrogen levels, revisions to water management operations to reduce spills during periods of fish migration, and provision at dams of additional facilities to bypass excess flows without increasing nitrogen levels. (EPA abstract)
(See also summary report W72-02160)

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17b. Identifiers

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NITROGEN SUPERSATURATION IN THE COLUMBIA AND SNAKE RIVERS

TECHNICAL REPORT NO. TS 09-70-208-016.2

Prepared by:

Robert L. Rulifson, Fishery Biologist

and

George Abel, P. E.

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAMS
SEATTLE, WASHINGTON
REGION X

July, 1971

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I - INTRODUCTION

Purpose

The purpose of this report is to describe the problem of dissolved nitrogen gas supersaturation including its effect on fish in the Columbia River and recommend solutions to the problem. This information is the status of present knowledge of the causes and effects of the supersaturation and is the basis for conclusions and recommendations for short and long range solutions on the Columbia and Snake Rivers. The same principles would apply to rivers in other areas as well.

Authority

Nitrogen in supersaturation has been shown to be a toxicant which causes mortalities to aquatic life and as such violates the criteria of the Interstate Water Quality Standards pursuant to the Water Quality Act of 1965.

In accordance with the responsibility of the Environmental Protection Agency (EPA) as set forth in Executive Order 11507 of February 4, 1970, Mr. William D. Ruckelshaus, Administrator, directed the Northwest Regional Office of the Environmental Protection Agency to prepare a report outlining the scope of the nitrogen supersaturation problem in the Columbia Basin with recommendations for its solution.

Scope

The information and data presented in this report are from studies and observations made on the Columbia and Snake Rivers. Figure 1 presents a map of the Columbia Basin. Some of the material presented is from published information but much of it is from progress reports and personal communications with representatives of the northwest state and federal fisheries agencies, the U. S. Army Corps of Engineers, North Pacific Division (NPD), and Bonneville Power Administration (BPA). While solutions are being sought to the problem of dissolved nitrogen supersaturation specifically on the Columbia River, the results of the studies are applicable to any location where water is spilled at dams or in some cases at natural falls.

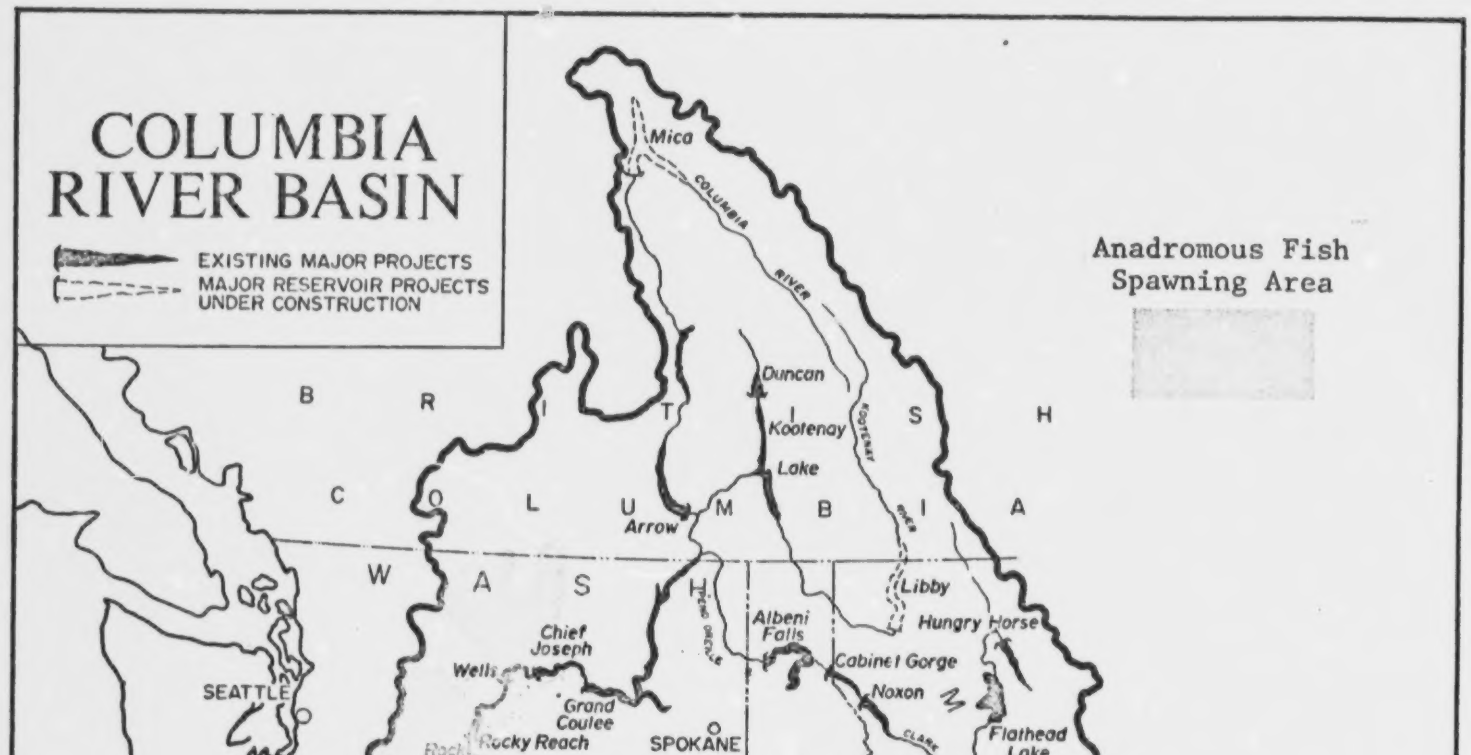

COLUMBIA RIVER BASIN
EXISTING MAJOR PROJECTS
MAJOR RESERVOIR PROJECTS UNDER CONSTRUCTION
Anadromous Fish Spawning Area
B R I T I S H C O L U M B I A
W A S H.
I D A H O
M O N T.
O R E.
N E V.
W Y O.
Mica
COLUMBIA RIVER
KOOTENAY RIVER
Duncan
Kootenay Lake
Arrow
Libby
Hungry Horse
Albeni Falls
Cabinet Gorge
Noxon
Flathead Lake
CLARK FORK
Chief Joseph
Wells
Grand Coulee
Rocky Reach
Rock Island
SPOKANE
SEATTLE
Wanapum
Priest Rapids
Lower Monumental
Little Goose
Lower Granite
Dworshak
HANFORD WORKS RESERVATION
Ice Harbor
PORTLAND
Bonneville
John Day
The Dalles
McNary
RIVER
SNAKE
SALMON RIVER
Hells Canyon
Oxbow
Brownlee
Pelton
DESCHUTES R.
WILLAMETTE RIVER
BOISE
Boise Projects
BOISE RIVER
C.J. Strike
American Falls
Palisades
Minidoka

Figure 1. Columbia River Basin Map

Report Organization

Chapter II presents a summary of the major conclusions and recommendations reached from the technical evidence. Chapter III gives a definition of the problem based upon the physical, chemical and biological evidence. Biological solutions or modifications are discussed in Chapter IV. A description and analysis of engineering solutions to the problem are described in Chapter V.

Fish Species

The Columbia River is inhabited by four species of Pacific salmon: sockeye salmon, chum salmon, coho salmon, and chinook salmon. The chinook salmon has distinct spring, summer, and fall races, while the other species do not. Another significant anadromous number of the salmonid family is the steelhead trout, which has both summer and winter races. Other anadromous fish of the Columbia Basin include several other species of trout, smelt, and American shad. Non-migrating fish species include the white sturgeon and several species of spiny rays (bass, crappie) as well as numerous other forage fish and predators.

The anadromous species seek out Columbia system waters far inland from the Pacific Ocean, historically reaching as far as Canada. They may presently be found in nearly all accessible tributaries where water quality conditions allow. Figure 1 shows the areas which remain accessible to anadromous fish since construction of the system of dams and reservoirs in the basin. Spawning occurs in the tributaries and in the only remaining unimpounded waters of the main-stem Columbia, the fifty-mile reach below Priest Rapids dam and through the Atomic Energy Commission's Hanford Reservation, which produces large numbers of chinook salmon.

The size of the Columbia River fish resource is most easily described in terms of the fish count over Bonneville Dam. In addition, it should be remembered that the Willamette River, Cowlitz River and smaller tributaries produce significant additional numbers of fish, and that the commercial and sports catch of the fish in these rivers and the Pacific Ocean from Alaska to California should be added to the Bonneville count. The thirty-one year record of upstream migrating fish passing over Bonneville Dam gives an annual average count of 705,875 salmon of all species and steelhead. The populations of the various species can be summarized as shown in Table I. The total numbers of fish entering the Columbia River in recent years is considered by fisheries agencies to be as high as in the 1930's. However, the size of the fish resource is now largely dependent upon artificial production. Also, the distribution of species and races making up the total has been changed by man's alteration of the river system.

TABLE I

AVERAGE ANNUAL UPSTREAM MIGRANT FISH COUNTS
AT BONNEVILLE DAM BY SPECIES
1938-1968

Chinook salmon	385,252
Sockeye salmon	100,777
Coho salmon (Three-year average 1965-1968)	77,289
Chum salmon	1,214
Steelhead trout	141,343

Source: Annual Fish Passage Report, Columbia River Project, U.S. Army, Corps of Engineers, North Pacific Division, Portland, Oregon.

All of the salmonids have similar life histories or cycles but each species and race matures at different rates, presenting differences in the duration and time of occurrence for the various stages of activity: spawning and incubation, rearing, juvenile migration, growth at sea, and adult migration. For example, salmon fry spend from a few weeks to over a year in fresh water before beginning seaward migration, depending upon the species and race. Similarly, the amount of time spent at sea also varies from less than one year for jack salmon[1/] to over five years, depending upon the species and race of fish. Figure 2 illustrates the time of occurrence during the year of the various stages of freshwater activity for the chinook, coho, and sockeye salmon, and for steelhead trout. As can be seen, migrating adults or juveniles can be found in the Columbia River throughout the entire year. However, the peak of migration occurs in a much shorter time. This is shown in Figures 3a, 3b, 3c and 3d, for four locations relative to the nitrogen concentration.

1/ Jack salmon are sexually precocious males.

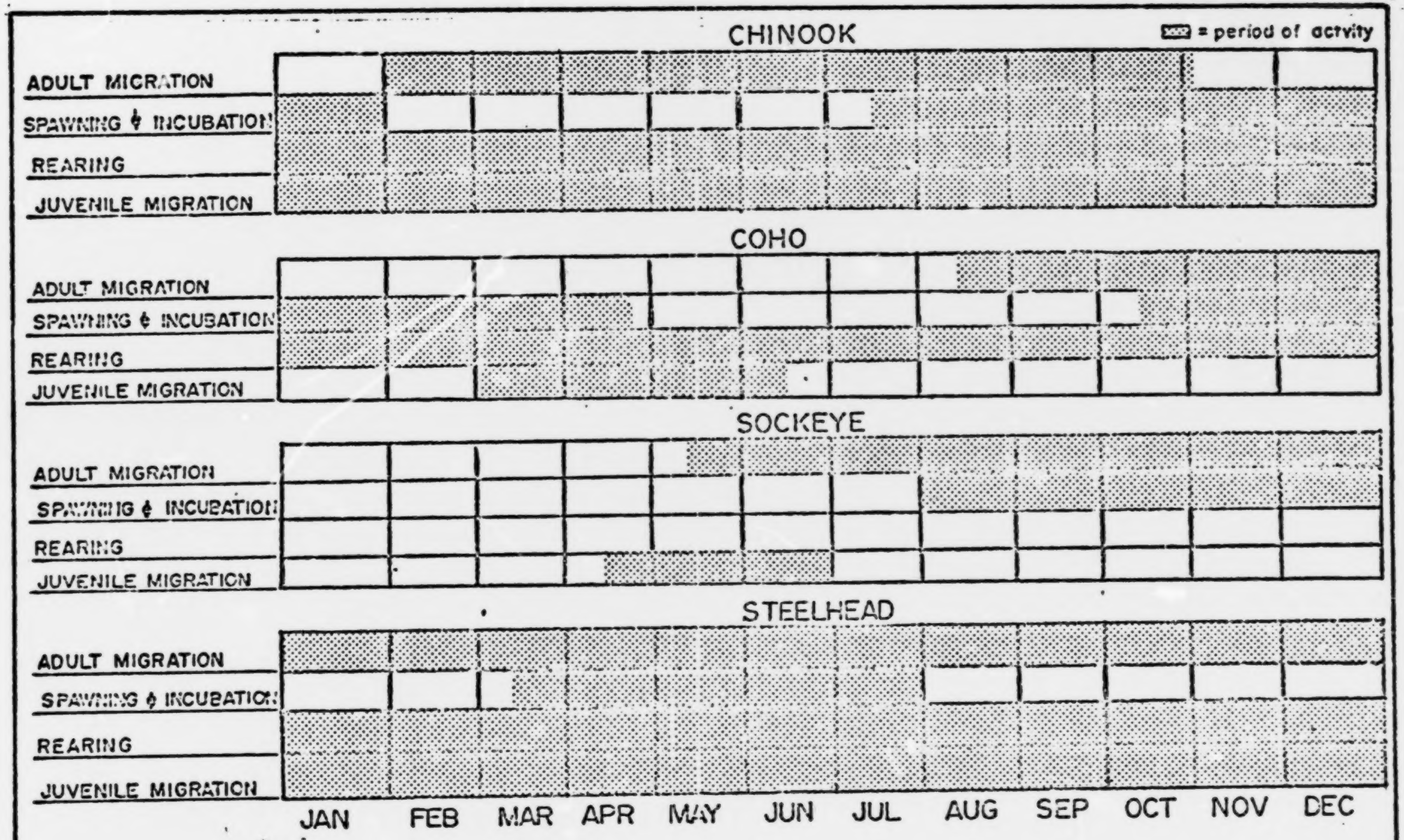


Figure 2. General Timing of Salmonid Activities, Columbia River

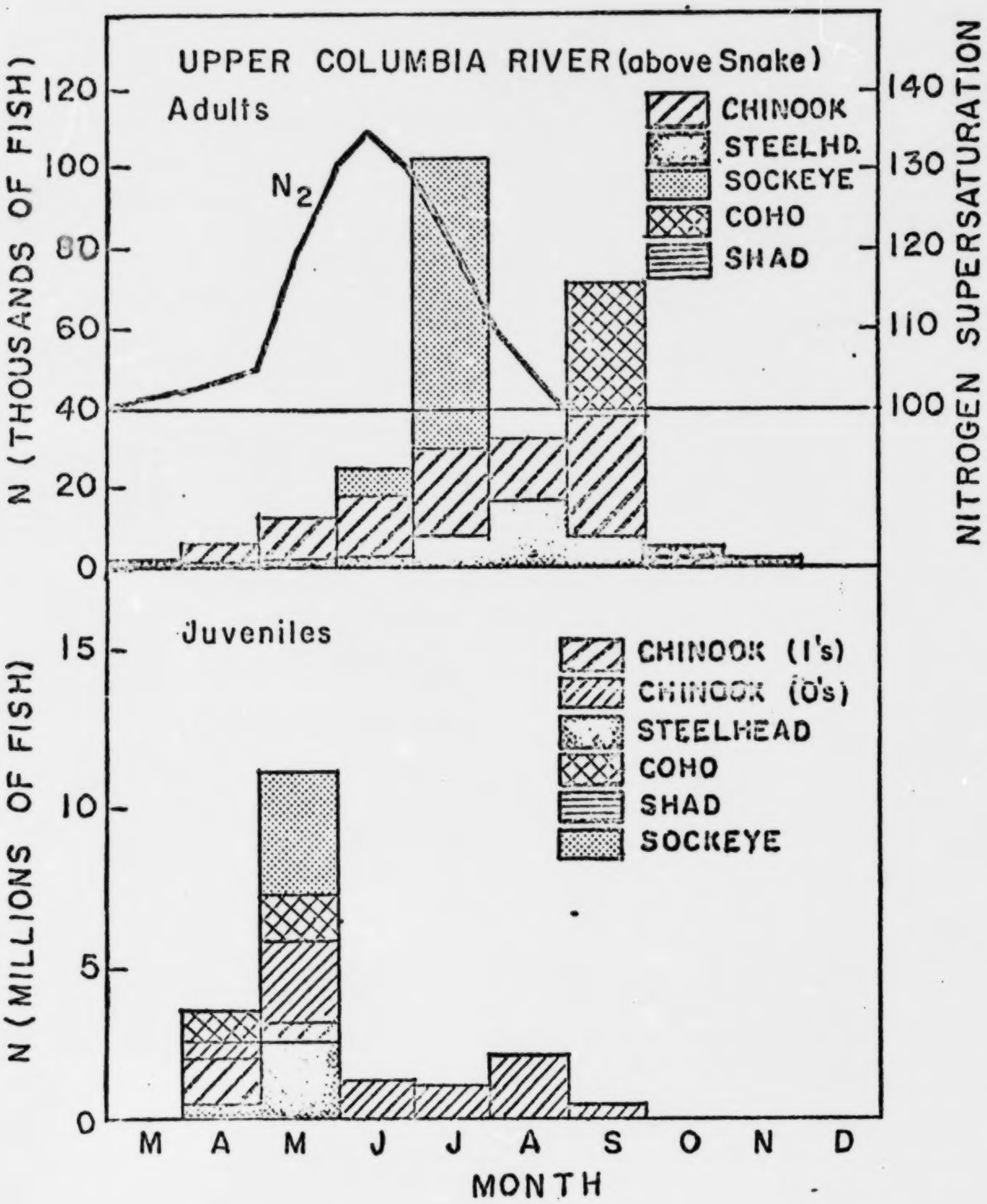


Figure 3a. Migration of Fish in Upper Columbia River in Comparison with Nitrogen Supersaturation

(Prepared by National Marine Fisheries Service)

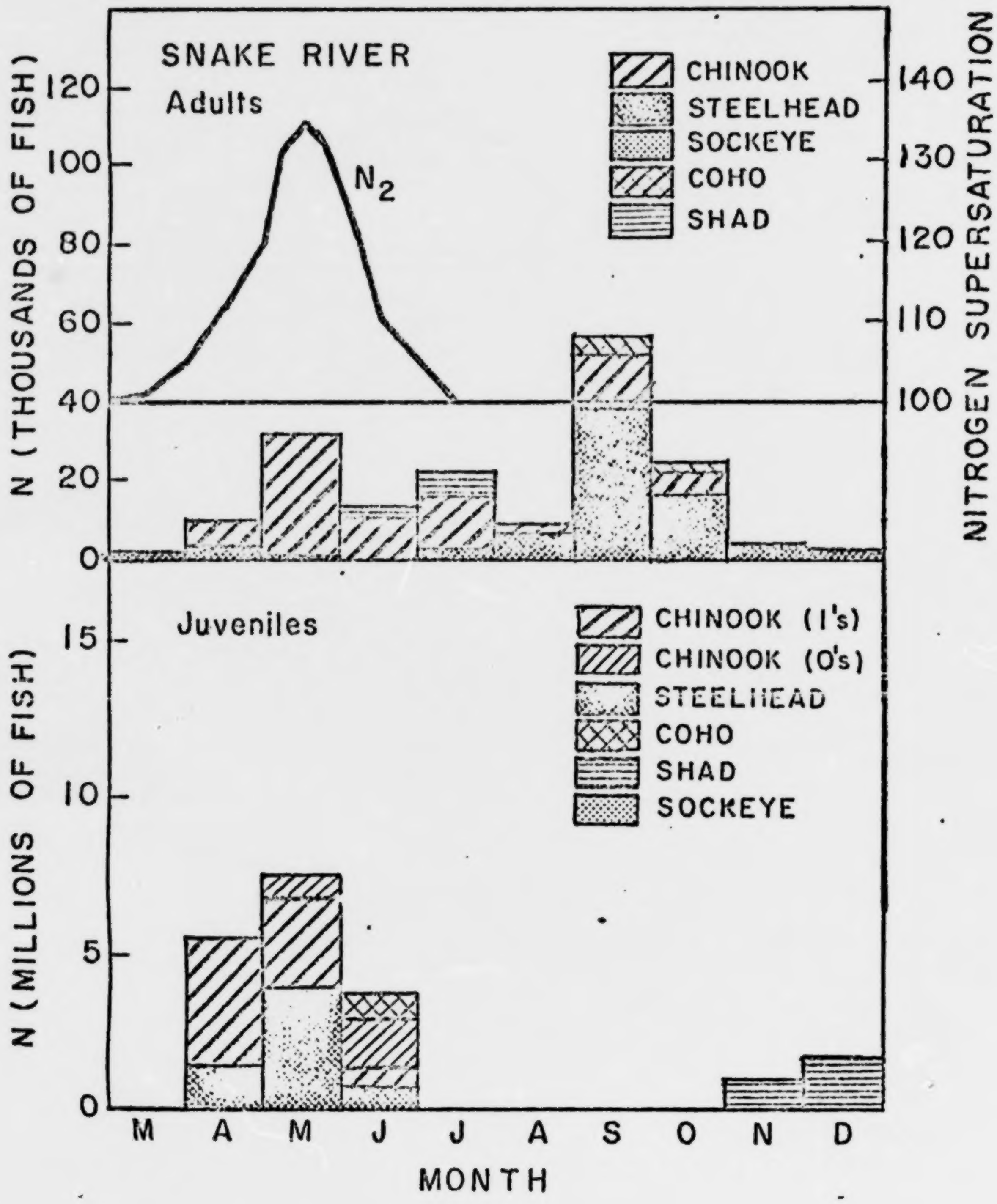


Figure 3b. Migration of Fish in Snake River in Comparison with Nitrogen Supersaturation

(Prepared by National Marine Fisheries Service)

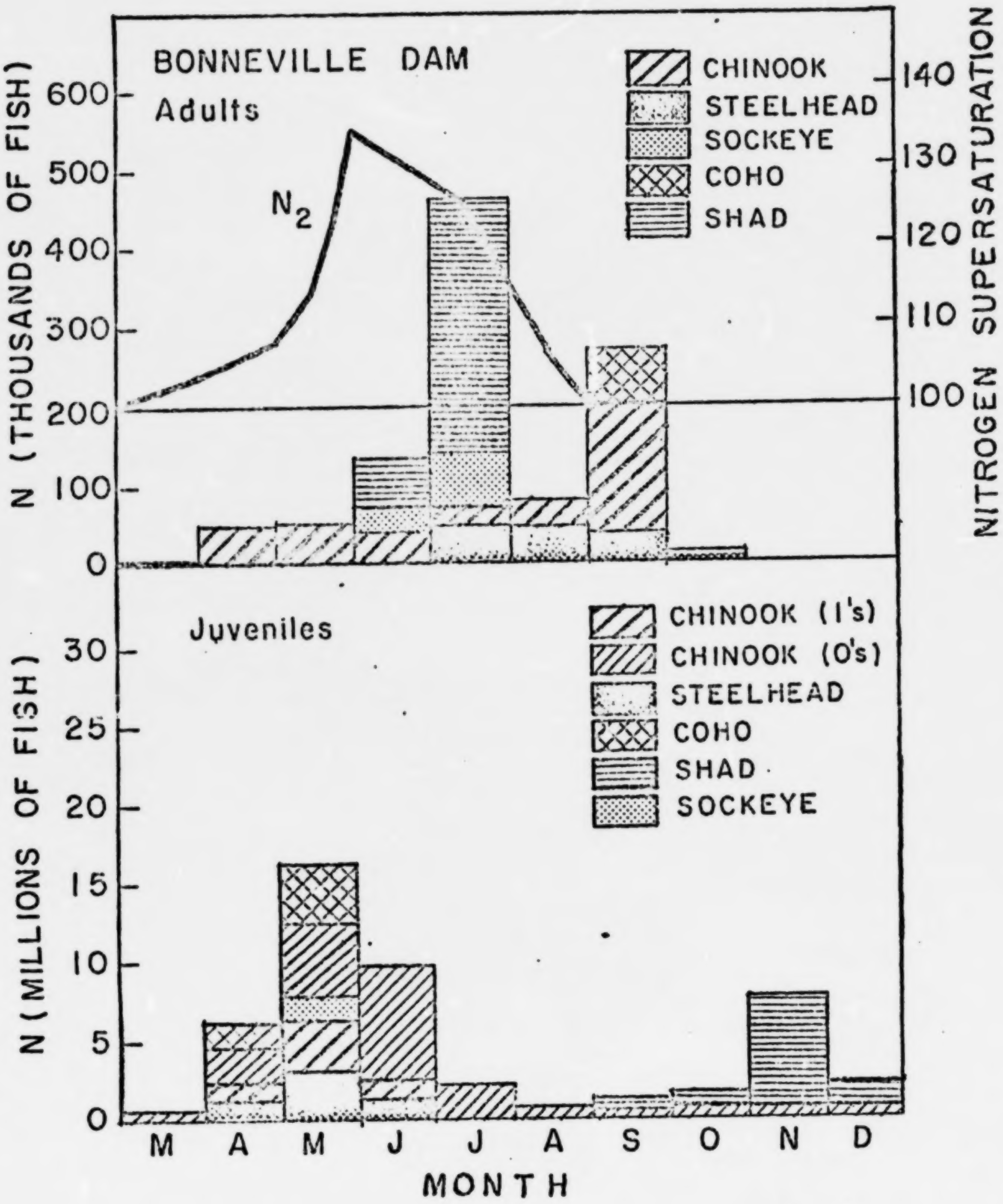


Figure 3c. Migration of Fish in the Columbia River at Bonneville Dam in Comparison With Nitrogen Supersaturation.

(Prepared by National Marine Fisheries Service)

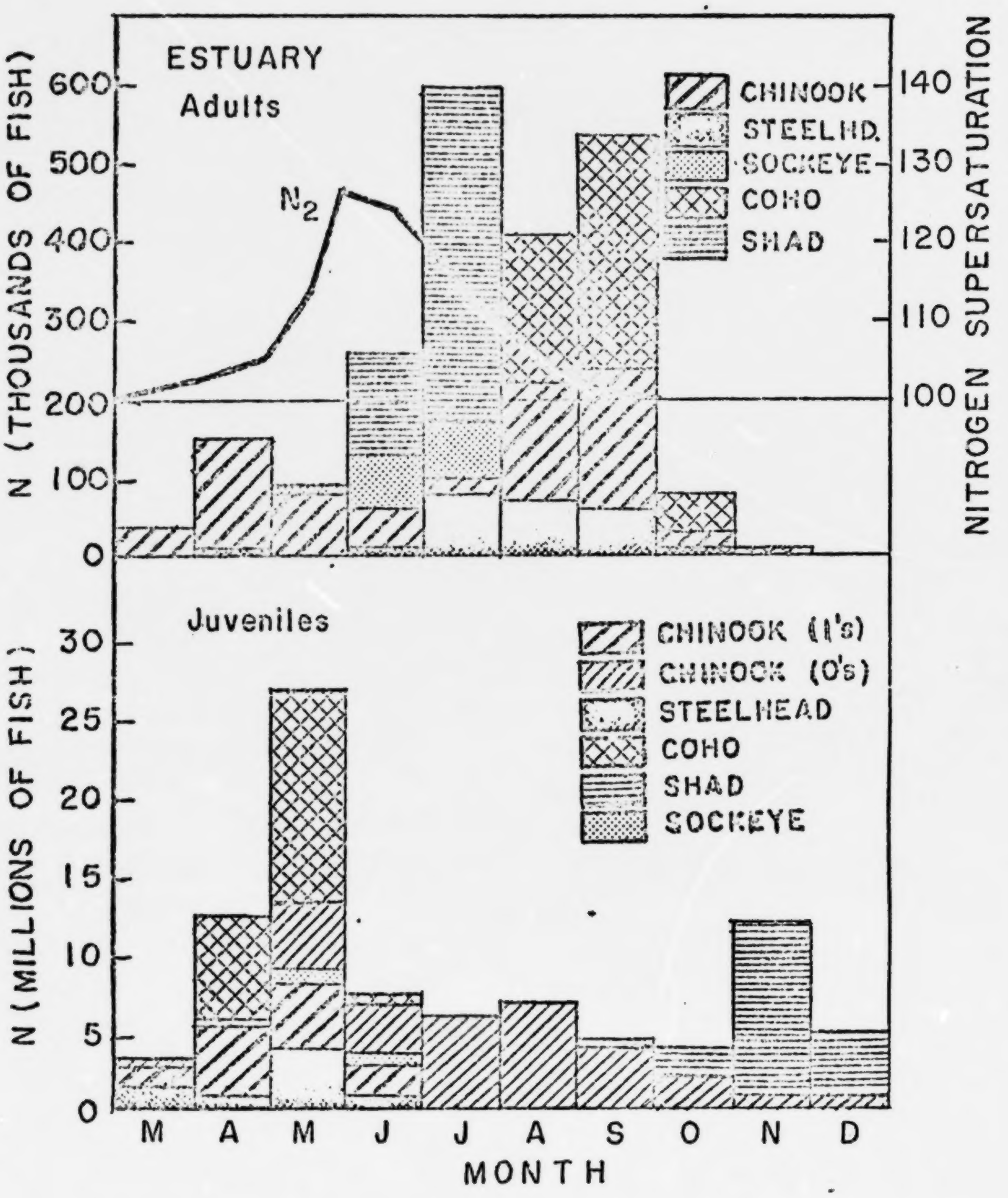


Figure 3d. Migration of Fish in the Columbia River Estuary in Comparison With Nitrogen Supersaturation

(Prepared by National Marine Fisheries Service)

FIGURE 6

The Physical Environment

The Columbia River remains accessible to anadromous fish as far upstream as Chief Joseph Dam, river mile (RM) 545. Throughout this length, two reaches are unimpounded: the estuary to Bonneville Dam (RM 145) and the Hanford reach between the head of McNary Pool (RM 347) and Priest Rapids Dam (RM 397). The remainder of the river is impounded behind nine run-of-the-river dams, with shallow reservoirs ranging from 54 to 165 feet in depth (Figure 1).

The surface runoff in the Columbia Basin is characterized by a typical snowmelt regime, with low flows during the late summer and winter and high flows during the spring and early summer. The volume of runoff in the Columbia ranks it as the fourth largest in the North American Continent; the average annual runoff at The Dalles, Oregon is 140 million acre-feet. Mean annual flow is 195,400 cubic feet per second (cfs); mean monthly discharges range from 95,700 cfs in January to 494,700 cfs in June.

With minor exceptions, the water quality of the Columbia River--other than temperature and dissolved nitrogen--is not considered detrimental to the fish resources. Water temperatures in the main stem Columbia River to Priest Rapids Dam range from maximums in the 70's during warm summer months to lows in the 40's and occasionally in the 30's during winter. Figure 4 shows water temperature and discharge profiles for various points on the Columbia River to illustrate general temperature and flow conditions.

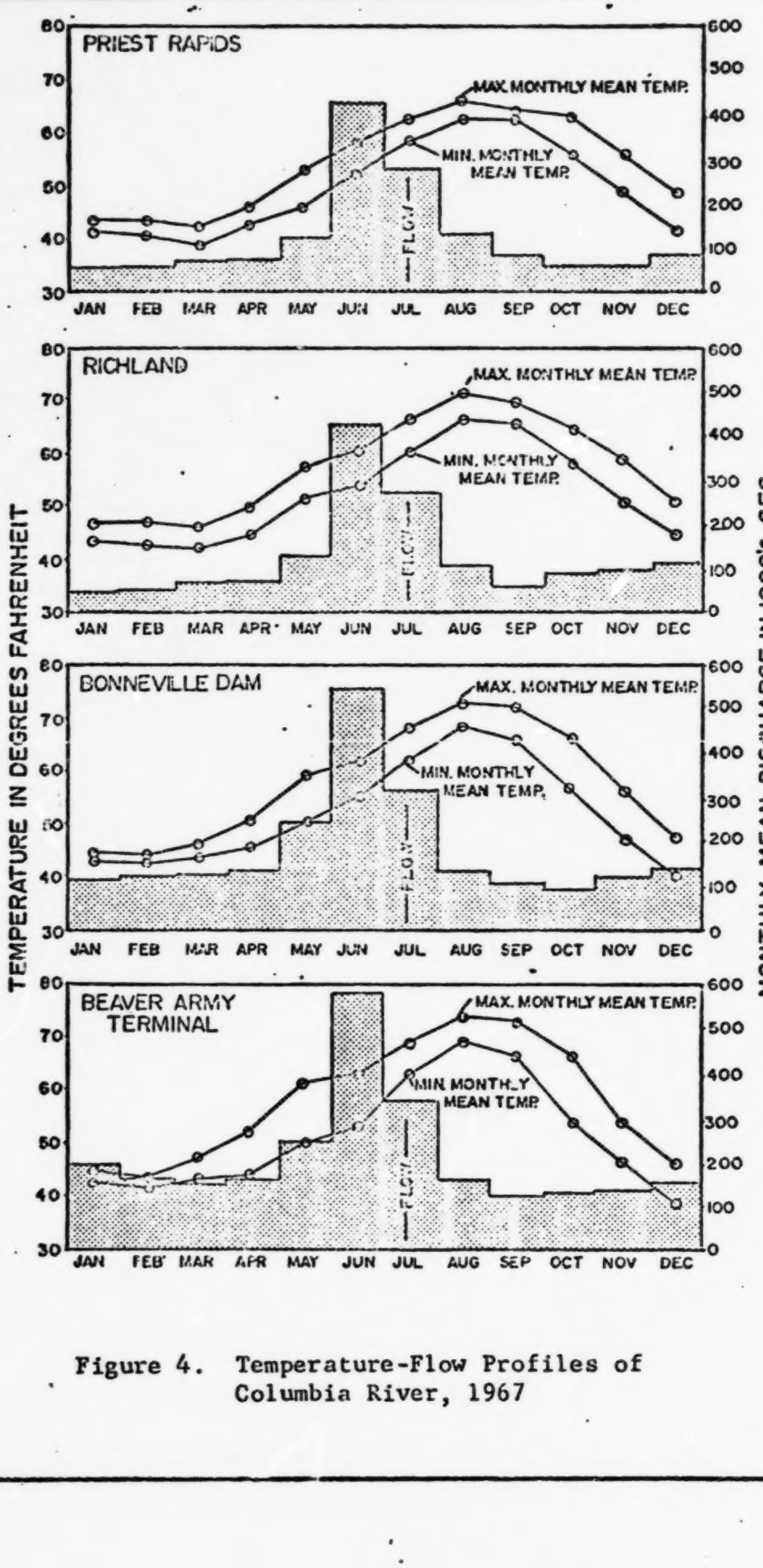


Figure 4. Temperature-Flow Profiles of Columbia River, 1967

II - SUMMARY

Conclusions

1. Essentially all reaches of the Columbia and Snake Rivers downstream from hydroelectric dams are significantly supersaturated with dissolved atmospheric gasses during periods of high spillway discharge.

2. The salmon and steelhead runs in the Columbia and Snake Rivers are seriously jeopardized under present conditions by supersaturation of dissolved gasses.

3. Nitrogen supersaturation conditions in the Columbia and Snake Rivers are caused at main stem hydroelectric dams when river flow must be passed over the spillways during the spring flood period. Nitrogen in the air is entrained in the flow as it passes over the spillway and, as the water plunges into the stilling basin below the dam, increased pressure forces the nitrogen from a gaseous state into solution in the water.

4. Water passing through the power-generating turbines or otherwise not exposed to the aerating effect of the spillways does not become supersaturated with nitrogen.

5. Nitrogen supersaturation levels above 105 percent produce symptoms of gas bubble disease in fish, and levels above 120 percent are lethal.

6. Nitrogen, because of its greater proportionate volume in air, has been measured and related to toxic effects on fish. However, it is known that the other atmospheric gasses are also involved in the gas bubble disease phenomenon.

7. Hypothetical flow regulation studies show that, with no operational or structural modifications for control of nitrogen, spillway flows at existing dams will be great enough to produce lethal levels of nitrogen supersaturation in years of average and higher river flows but not in low flow years. An average year is one with flows which, statistically, would be equalled or exceeded one year out of two. Although it is not certain at what specific river flow levels nitrogen problems begin to occur, it is apparent that the threshold level is somewhere between low and average flows.

8. Under present plans to expand the Columbia Basin hydroelectric system through the year 1980, the volume of spills at the various projects will be reduced. However, without additional control measures, the reduction in the volume of spills will not be great enough to reduce nitrogen supersaturation to levels considered safe for fish during even a year of average flows.

9. Installation of slotted gates and bypass of flow through empty turbine bays in the Lower Snake River dams will further reduce the spills in that river, but nitrogen levels hazardous to fish will still occur in years of average or higher flows.

10. A basic requirement to a solution of the problem is to devise methods whereby volume in excess of flows through turbines can be passed by dams without entraining atmospheric gasses.

11. Lower Granite Dam, presently under construction, will add to already critical nitrogen problems in the Lower Snake River unless the completed project includes provisions for passing flood flows without entraining atmospheric gasses.

12. Unless provisions can be made to pass maximum flows through turbines, installation of turbine generator units in dams before they are needed to meet regional power demands may eliminate flexibility in the use of the otherwise empty turbine bays to bypass flow, and thus may aggravate the nitrogen problem.

13. Increasing use of the hydroelectric system for peak power generation could cause wide diurnal fluctuations in the amount of spilling unless pumped storage, pondage, and thermal power facilities are effectively used to reduce the fluctuations.

14. The critical nature of the problem in 1971 caused an unprecedented level of coordination and cooperation among the Corps of Engineers, Bonneville Power Administration, and the Northwest fishery agencies in developing partial immediate solutions to the problem.

15. Flexibility within the federal dam-power complex contributed much to the success of a flow reduction program in April 1971 to make the best conditions for a mass hatchery fish release. Although the program required increased coordination, the cost to the Government was minimal. Continued annual use of the flexibility of the federal system is a necessary partial solution to the nitrogen problem.

16. The Washington Public Utility Districts and Idaho Power Company cooperated in the nitrogen reduction program in 1971, but

even greater interchange between the federal and non-federal systems should be permitted by necessary changes in regulations and licenses. It is necessary to include the Federal Power Commission in future planning.

17. Trapping of downstream migrants from the Snake River and transport to the estuary are a necessary partial solution to the problem. Additional trapping at McNary Dam would salvage fish from the Upper Columbia and residual from the Snake River.

18. Delay in passage of adult upstream migrants below dams and in fishways is a significant factor in increasing mortalities from direct or secondary effects of gas bubble disease. Changes in the water management system within allowable flexibility could relieve the adult fish delay problem.

19. Nitrogen conditions are more severe at some dams than at others because some necessitate more spilling than others. Also, spillway and stilling basin designs have an effect. Dams newly completed have required almost complete spilling of flood flows until the power-generating turbines are installed -- for example, at John Day Dam, completed in 1968.

Recommendations

1. The states of Oregon, Washington, and Idaho, together with the Environmental Protection Agency, should initiate immediate action to establish a water quality standards criterion for dissolved nitrogen in the Columbia and Snake Rivers.

   a. The standards criterion should establish a maximum allowable concentration of dissolved nitrogen in the Columbia and Snake Rivers at 110 percent of saturation based on analytical procedures presently being followed by the National Marine Fisheries Service.

   b. Immediate research and development efforts should be initiated to develop a method to measure total dissolved gas partial pressures to be related to dissolved gas concentration data.

c. Expanded research and development efforts are also needed to relate dissolved gas partial pressure data to effects on fish. The results of these studies may be used for future reviews of the standards criterion for nitrogen.

d. The Environmental Protection Agency should work with the National Oceanic and Atmospheric Administration to develop an effective regional program for dissolved nitrogen monitoring in the Columbia and Snake Rivers. A formalized monitoring program will be needed to measure progress towards compliance with the standards criteria.

2. A regional council should be established immediately to make specific recommendations on administrative, legislative, and policy actions required to implement an effective nitrogen control program. Membership on the council should include high-level representatives of regional environmental, fisheries, water resource development, and water management agencies. The regional council for nitrogen control should periodically report on its review of the nitrogen supersaturation problem, assessment of progress towards control of nitrogen supersaturation effects on fish, and recommendations for further action to the council's constituent agencies, the Council on Environmental Quality, and other affected agencies. Elements of a regional nitrogen control program should include the following:

a. Nitrogen supersaturation reduction program.

(1) Maximum utilization of the flexibility of the regional system of reservoirs and power-generating facilities to reduce spills during periods of fish migration.

(2) Provision at each dam of a method to pass any flows which are in excess of those required for power generation through or over facilities which will not entrain excessive atmospheric gasses in the water. The Corps of Engineers should be fully supported in their suggested program of structural modifications for this purpose at their projects and others.

(3) Revisions of generator installation schedules and construction methods to maintain maximum bypass capability at dams during the period of construction. Congressional authorization and appropriation schedules may need to be adjusted appropriately.

b. Expanded program to physically limit exposure of migrating juvenile salmonids to nitrogen supersaturated waters.

(1) Expand the installation and operation of fish collecting screens in all turbine units at Little Goose Dam by April, 1972. The collection screens could later be transferred to Lower Granite Dam at the time of its completion. Lower Granite should be designed to allow the installation and operation of both skeleton bays and fish collection screens.

(2) Install and operate fish collection screens in all turbine units at McNary Dam by April, 1973.

(3) Continue to expand the program initiated in 1971 to make mass fish hatchery releases during periods of reduced nitrogen. Transport fish, where feasible, for release in the Lower Columbia River below Bonneville Dam.

3. Any new dam in the Columbia Basin must include facilities for adequate control of nitrogen supersaturation. Specifically, adequate controls at Lower Granite Dam (now under construction) must be provided before completion of this project. The design goal for these control facilities should be to maintain dissolved nitrogen concentrations downstream from the project below 110 percent of saturation in a ten-year flood.

Additionally, existing plans for further alteration or expansion of the Columbia River water resource development system, including hydroelectric power-peaking aspects of the hydro-thermal program, should be reviewed by the river management agencies to insure that the plans are consistent with the above strategy for abatement of nitrogen supersaturation problems. In order that control strategies can be developed and implemented on a timely basis, this review should be completed and provided to the regional nitrogen control council by January, 1972.

III - DESCRIPTION OF THE PROBLEM

The Washington Department of Fisheries found in the early 1960's that levels of dissolved nitrogen (N_2) supersaturation in the Columbia River were sufficiently high to cause problems with salmon runs. Previous experience with nitrogen supersaturation related the problem principally to hatchery water supplies (Rucker & Hodgeboom, 1953). Following this discovery, a conclusion was reached by the technical staffs of the Northwest fishery agencies that if nitrogen was an important cause of fish mortalities, the problem would eventually be eliminated with the completion of upriver dams which would eliminate most of the spill. As more information was assembled, this conclusion proved to be erroneous.

This problem was recognized by the Environmental Protection Agency as one of great magnitude which threatens the continued existence of runs of valuable salmon and steelhead on the Columbia River. The Washington State Department of Ecology has likewise recognized this problem and has asked assistance of EPA and the Corps of Engineers in its solution.

Physical Evidence

Dissolved nitrogen saturation levels as high as 125% were observed in the spring of 1965 at some sites in the Columbia River by the Washington Department of Fisheries and the Bureau of Commercial Fisheries. The adverse effects of saturation levels of 125% are well documented. Therefore, additional surveys were made in 1966-67 to determine the cause of supersaturation and seasonal variations and to determine the effect on adult and juvenile salmon (Ebel, 1970C). Water samples were collected in 1966 from 26 stations between Grand Coulee Dam forebay and the estuary at Astoria. The samples were analyzed for dissolved nitrogen and the results of four series are shown in Figure 5. The evidence shows that supersaturation in the Columbia River is caused primarily by spillways at dams. During periods of the year when spilling normally does not occur, the saturation level is near normal (100%) but increases to levels as high as 140% during periods of spill. To further test the effect of spilling on saturation values, a series of tests was run at Bonneville Dam in March 1966, a period when normally there would be no

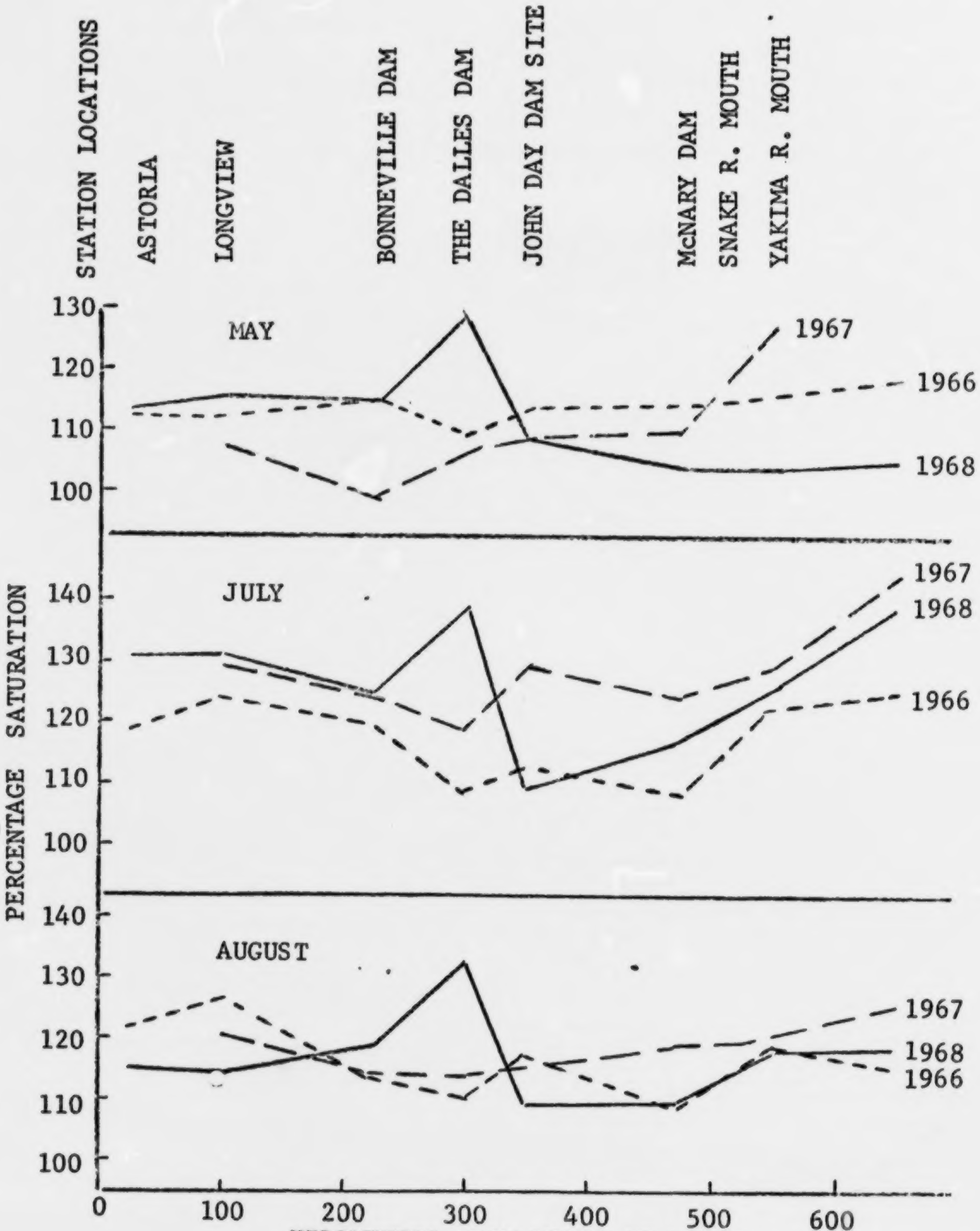


Figure 5. Comparison of Percentage Saturation of Dissolved Nitrogen in Forebays from Priest Rapids Dam to Mouth of Columbia River, May, July, and August. 1966 (short dashes), 1967 (long dashes), 1968 (solid line).
(Beiningen and Ebel, 1971)

spill (Ebel, op. cit.). The results show that "during the spill tests, concentrations below the spill increased to 125% saturation, whereas concentrations in the forebay and below turbines remained over 100%."

Subsequent studies in 1967 and 1968 confirm the general findings of 1966, that during periods of spill the nitrogen levels increase. These data are included in Figure 5. One observation of importance is that equilibration of the dissolved nitrogen concentration in the reservoirs between dams is very limited, probably because of lack of circulation in surface waters. An exception has occurred in John Day Reservoir, possibly because of its greater length. A greater amount of water passing over the spillway at John Day in 1968, the year of initial operation, caused a drastic increase in nitrogen in its tailrace. Peak nitrogen concentrations ranged from 123 to 145%. The effect of this increase on The Dalles Reservoir downstream is shown on Figure 5. With more water passing through the turbines and less over the spillway at John Day Dam in 1969-70, the effect is less severe. Surveillance of the Columbia and lower Snake River has continued in 1970 and 1971 by the National Marine Fisheries Service (NMFS), (formerly Bureau of Commercial Fisheries) funded by the Corps of Engineers. Results confirm those of previous years, that during periods of excess spill, dissolved nitrogen levels increase below the uppermost dam (Grand Coulee) and remain high to the mouth of the Columbia. The runoff started earlier in 1971 than in prior years and by mid-April the nitrogen concentration had reached dangerous levels. Data collected by the NMFS for 1964-69 has been published by Beiningen & Ebel (1971).

The EPA has sampled for nitrogen upstream and downstream from Oxbow and Hells Canyon Dams on the Snake River in 1969, 1970, and 1971. The results of analysis show either a subsaturation or slight supersaturation in Brownlee Reservoir, but a moderate to high increase in the tailrace and in the stream reach below depending on the volume of spill at the upstream dams.

Two sampling runs in April and May, 1971, from river mile 239 below Hells Canyon Dam downstream to Lewiston (RM 141) and Little Goose Reservoir (RM 72), respectively, give a picture of variable nitrogen concentrations, with a general decrease downstream indicating slow equilibration. Levels from 120-133% were observed below Hells Canyon Dam decreasing to near 110% at Lewiston and increasing again in Little Goose Reservoir.

The reason for the variability cannot be explained at this time. Data from major tributaries (Grand Ronde and Imnaha Rivers) near their mouths, show either equilibration or low supersaturation. The Salmon River, on the other hand, contained nitrogen from 110-114% and the Clearwater River showed 112% saturation.

Washington Department of Fisheries reported what they considered to be wide variability of nitrogen saturation in the forebay of Chief Joseph Dam, (Meekin, 1971). Harvey and Cooper (1962) found considerable variation in oxygen saturation during one day and with the level of discharge constant below a falls on a natural stream. They thought changes in barometric pressure and temperature were responsible.

Biological Evidence

Observations of Dead Fish and Fish Showing Symptoms of Gas Bubble Disease

A number of observations of dead and affected adult and juvenile salmon and steelhead have been observed and recorded on the Columbia River in recent years. While some of the evidence is circumstantial, the number of observations and circumstances leave little doubt that dissolved nitrogen supersaturation is responsible. The best summary of these observations is contained in an address to the Tri-State Governors meeting on March 23, 1971 (Schoning, 1971). The most convincing evidence of the severity of the problem is the results of the juvenile salmon marking study on the Snake River where mortalities of downstream migrants were less than 5% prior to completion of Lower Monumental and Little Goose Dams; after completion in 1970, the mortality to naturally reared marked fish was estimated to be 70% and largely attributed to nitrogen caused problems. Mortality to hatchery reared chinook has been demonstrated to be even higher (Raymond, 1970B).

External symptoms of gas-bubble disease include: eyes distended and hemorrhaged; bubbles in the subcutaneous layers surrounding the eyeball; enlarged vesicles between the epithelium and connective tissue in the roof of the mouth and on the outside of the operculum (Beiningen and Ebel, 1970); (Bouck, Chapman, Schneider, and Stephens, 1970B).

Large numbers of adult salmon bearing characteristic symptoms of gas-bubble disease have been observed on several occasions. The most serious incident occurred at John Day Dam in 1968, the first year of operation of the fish facilities when no turbine facilities were operational and all discharge was by way of the spillway. Three separate delays were recorded during the 1968 migration season, two at John Day and one at The Dalles Dam. The highest count of dead fish observed after a delay at John Day Dam was 13 sockeye and 365 chinook on July 29. Fish Commission of Oregon estimates place the loss between Bonneville and McNary Dams at over 20,000 summer chinook salmon. High nitrogen concentrations were implicated in this loss.

In the opinion of Bouck et al. (1970A), the immediate mortality may not be the most serious consequence of supersaturation to adult salmon. In connection with a thermal effects study on adult salmon, Bouck et al. (op. cit.) removed adult sockeye salmon from the Columbia River during a period of high nitrogen supersaturation and subjected them to air equilibrated water with temperatures ranging between 50 and 70 F (10 - 22.2 C). Loss of eyes or blindness which was attributed to gas-bubble disease occurred in 1/3 to 2/3 of the fish. The sublethal damage such as blindness may be essentially equivalent to death in terms of damage to natural reproductive potential (Westgard, 1964; Bouck et al., op. cit.). The disease may have been responsible for a 57% below average number of spring chinook reaching the Snake River spawning grounds in 1968 in spite of a record high number of adults passing from the Columbia into the Snake. Coutant & Genoway (1968), concluded that the harmful effects of high water temperatures on adult salmon are worsened by prior or simultaneous exposure to nitrogen supersaturation. The survival time of jack chinook acclimated to 62.2 F (17C) which were subjected to 71.6 F water (22C) was drastically shortened when the warmer water contained dissolved nitrogen gas levels in excess of 115% of saturation. Regardless of the nitrogen levels in the warmer water, acclimatization of the fish to water supersaturated with nitrogen reduced subsequent survival time.

Delay in Passage

Studies by the Fish Commission of Oregon at The Dalles and Priest Rapids Dams show a significant delay in passage of adult salmon and steelhead on weekdays as compared to weekends (Charles Junge, personal communication). The delay is related to the effect of the peaking type of power generation. It seems reasonable to assume that any delay of fish below a dam or in a fishway during a period of high nitrogen conditions will increase their exposure. This would be particularly harmful if the delay was in a fishway where the fish are forced to stay in relatively shallow water.

Live Cage Tests

The question of the compensating factor of depth when nitrogen supersaturation is present has been explored by the National Marine Fisheries Service in experiments at Priest Rapids Dam, 1967, and at Ice Harbor Dam, 1970 (Ebel, 1970B; Ebel, 1970C). The results show generally that fingerling salmon held at the surface or in cages at depths up to 7 feet suffer excessive mortalities approaching 100% while fish in cages at about 10 feet depth do not suffer mortalities due to the protection of increased hydrostatic pressure. In a cage where the fish were allowed to sound at their own volition to 15 feet, the mortality was reduced but still ranged from 40 to 68 percent after 7 days exposure. This test may approach actual conditions the fish may experience in the river and also indicates the fish may be unable to detect the nitrogen and thus avoid it.

Problems in Other Areas

The problem of nitrogen supersaturation is not restricted to the Columbia and Snake Rivers. It has been reported by the Fish Commission of Oregon as responsible for a fish kill at a salmon rearing station (Dexter) during a period of high spill at an upstream dam. Two other instances of extensive fish kills were the result of air being drawn into a pipeline (Wyatt, 1969). Harvey & Cooper (1962) reported the problem from a Canadian stream used for a hatchery water supply. A falls upstream caused the supersaturation. Others have reported the problem associated with hatchery operations (Rucker & Hodgeboom, 1953; Rucker & Tuttle, 1948; Westgard, 1964; Harvey & Smith, 1961; Marsh & Gorham, 1904).

Safe Level of Nitrogen

A number of experiments beginning with Marsh & Gorham (1904) have been conducted to determine safe levels of dissolved gasses for hatchery use. Nitrogen is the usual cause of gas embolism because it is the least soluble of the three principal gasses in air and is not removed from the dissolved state by chemical combination with blood components. Comparison of results and methods of different investigators is difficult. However, two researchers agree that nitrogen saturation of less than 110% causes symptoms of gas-bubble disease or death to salmonids (Harvey and Cooper, 1962; Shirahata, 1966). Others report levels between 110% and 120% as not satisfactory (Rucker and Tuttle, 1948; Rucker and Hodgeboom, 1953). Researchers are agreed that dissolved nitrogen concentrations above 120% of saturation are lethal. The sublethal effects of chronic exposure to the lower concentrations is not well understood and requires additional research.

Pathology

A number of investigators have described the gross symptoms of gas-bubble disease: bubbles appearing under the skin and in the fins and eyes of fish, but Pauley and Nakatani (1967), were the first to describe the histopathology. Tissues from many organs and parts of chinook salmon fingerlings that exhibited a light but detectable case of gas-bubble disease from external symptoms were examined histologically. All tissues of the diseased fish except the hearts and stomachs exhibited definite histopathological changes with rupture of tissue cells and red blood cells in the gills and kidneys. Tissues were swollen and filled with fluid. They particularly noted the swollen condition in the roof of the mouth which seems to be characteristic of this disease. Other investigators have noted similar changes with the exception of the roof of the mouth due to chemical toxicity. All investigators are in agreement that death from acute exposure is caused by blockage of vital organs and tissues by gas emboli. An embolism reaching the heart causes instantaneous death. One aspect of the disease that puzzled Pauley and Nakatani (1967) and other investigators is the apparent recovery of diseased fish when removed from the high nitrogen environment.

While no work has been done to prove the point, pathologists are in agreement that microbubbles known to be present in turbulently mixed water probably have no part in the pathology of gas-bubble disease and only dissolved nitrogen is involved. Shirahata (1966) determined the composition of gas which accumulated in abdomens of his test fish and found it similar to that of gas bubbles in rearing water and of atmospheric gas. He believes the gas in abdomens may originate from the free gas bubbles in water. If this is the case, the gas transfer cannot take place directly but must pass across two membranes.

One conclusion that can be reached from the limited information available is that the etiology of gas-bubble disease is incompletely understood and is in need of further research, particularly to learn the effects of chronic exposure to low levels of supersaturated gasses.

Embolism

It is agreed that gas bubble disease is caused by the formation of gas emboli (bubbles) within the fish. The blood dissolved gas level closely follows that of the surrounding water. If water is supersaturated, the greater partial pressure of atmospheric gasses in the water will cause the blood and tissues to also become supersaturated. One idea that has been suggested for the formation of bubbles within blood is because of the turbulence of flow or pressure drop within the circulatory system. That this could occur in fish seems unlikely considering the low hydrostatic pressure under which most fish circulatory systems operate. A hypothesis more reasonable than the blood turbulence idea is presented by a Battelle-Northwest physiologist (Mark Schneider, personal communication). He believes that blood is an unstable liquid offering many sites for emboli formation including protein and lipid molecules, red blood cell membranes and gas micronuclei. Hill's (1967) showed that fluids supersaturated with gas are inherently unstable and will revert to a stable thermodynamic state with the release of free gas bubbles if given a site for initial bubble formation. The gas micronuclei may always be present in blood but are so small that they themselves never cause embolism and only become a problem when the blood is supersaturated and therefore unstable. The question of gas micronuclei was extensively considered by Harvey (1951). He had previously said the origin of gas micronuclei was obscure but an important consideration (Harvey et al., 1944). Evans & Walder (1969) demonstrated in their work with shrimp that microbubbles are involved in formation of larger internal gas bubbles upon decompression of the animal. They also showed that formation of new microbubbles is associated with muscular activity. In Schneider's hypothesis, he assumes that with temperature and pressure constant there is a threshold level of blood dissolved gas below which no emboli will form.

The fish gas bubble disease has been described as closely related to the bends experienced by human divers following rapid decompression. Technically, the "bends" (Caisson disease) is a condition of embolism in a human diver caused by too rapid decompression of air. Distinction should be made that embolism in fish is similar to the "bends" but has important differences. The one principal and significant difference is that fish held in supersaturated surface waters readily develop symptoms of gas bubble disease and lethal emboli with no change in pressure or temperature. Further research may determine that an embolism in fish may be caused by any one or a combination of the factors discussed above.

Chemistry and Physics

Gas supersaturation in water can occur from a temperature increase such as in the thermocline of a lake (Harvey, 1967) or from turbulent mixing of air with water (Harvey & Smith, 1961). A turbulent stream can have a supersaturation by air injection, and this is observed to occur in the open ocean, presumably the result of wave action (Craig & Weiss, 1971). Ground water can be very high in dissolved nitrogen and may cause problems when used for fish culture (Marsh & Gorham, 1904).

The problem of gas supersaturation of primary concern on the Columbia and Snake Rivers is caused by the entrainment of air in water as it plunges over the spillways of dams. The air bubbles are carried to considerate depth in the stilling basin (tailrace) of a dam, and the increased pressure forces some of the gasses to go into solution. In accordance with Henry's Law, gasses enter solution in relation to the products of their partial pressures and solubilities. In air-equilibrated water, oxygen has about one-half the concentration of nitrogen because oxygen is twice as soluble as nitrogen but in air has only one-quarter of its partial pressure.

Air bubbles carried to depth in water become smaller as the water pressure increases and their gasses enter solution. As the bubble becomes smaller, its internal pressure becomes greater, thereby forcing the gasses to go completely into solution. The nitrogen would enter solution four times as plentifully as oxygen instead of twice as readily as under surface or atmospheric equilibrium; and nitrogen saturation, expressed as the percentage of gas saturation would tend to exceed that of oxygen. Temperature can be an important factor in gas supersaturation. For example, the solubility of nitrogen at 0 C is 55 percent greater than at 20 C (Weiss, 1970B). Thus, warming of water, without corresponding re-equilibration with the atmosphere, as on the surface of a reservoir, can cause significant supersaturation.

Methods of Analysis

There are four methods used to study the solubility of gasses in liquids. These methods are briefly described as follows:

1. Manometric-Volumetric methods. The most extensively used methods measure an amount of gas as it is absorbed into

a degassed solvent (Ostwald method). At present, this is also the most accurate approach to most gas solubility work. Another method extracts and measures gas from a saturated solvent (Van Slyke method).

2. Mass spectrometric. Gas is stripped from sample and analyzed by mass spectrometry.

3. Gas chromatographic. Gasses from a liquid sample are extracted, separated in a chromatographic column and detected, usually by differences in thermal conductivity.

4. Chemical. Not used for nitrogen; the Winkler method is used for oxygen determinations.

The Van Slyke method of analysis has recently been the method most extensively used in biological investigations for determining nitrogen, plus traces of inert gas; however, it takes 30 minutes to analyze a sample and requires bulky and delicate equipment that is difficult to move. It is used by the NMFS as a standard for the gas chromatograph which requires seven minutes for each sample and therefore more useful for large numbers of samples, as in the current investigations. The results are detected and recorded automatically. The need for equipment that is more stable and more portable has prompted the development of a prototype portable gas monitor by the EPA. It is a modified gas chromatograph which requires four minutes to run a sample, can be run from a portable gasoline-powered generator, and has a number of advantages for field use. A few technical problems prevent its being completely operational at this time.

Problems of Analysis

Due to the lack of portable equipment for analysis, it has been necessary to collect field water samples and transport them to a laboratory for gas analysis. It has been standard procedure to ice the water sample immediately after collection to increase the solubility and thus minimize the ex-solution of supersaturated gasses that may occur between collection and analysis. This error is believed to be small, however, some samples collected by EPA have been observed to have formed gas bubbles during iced storage in the laboratory prior to analysis. This gas accumulation may either be the result of suspended air bubbles coming out of suspension, or of supersaturated concentrations in excess of solubility at ice temperatures. It is interesting to note that the water samples collected from Brownlee Reservoir did not contain the free gas bubble in the sample bottle, while all samples collected downstream from Oxbow and Hells Canyon did contain the gas bubble.

One theory for the high dissolved gas levels found in the Columbia River is the presence of microbubbles in the water that are high in nitrogen concentration and virtually non-equilibrating (Spink, 1971). Work on this phenomenon remains incomplete.

The solubility of nitrogen, based on measurements made during the past ten years, is known to well within 0.5 percent (Weiss, 1970). However, most saturation values reported for the Columbia River studies have been calculated from the solubility data of Fox (1909), which may be as much as 2 percent in error. As an additional complication, many workers have calculated the solubility of air nitrogen from the solubility coefficients using a dry rather than moist atmosphere. Saturation values calculated in this way may be up to 2 to 3 percent too low, depending on the temperature. Measurements of nitrogen concentrations by the Van Slyke method require correction for argon and other inert gasses, which are not distinguished from nitrogen by this method. In many cases this has not been done or has been done incorrectly, resulting in nitrogen concentration values up to 2 percent too high. In many cases, workers have reported concentrations in mg/liter rather than in ml (STP) / liter--a unit which is more desirable since it is closer to the actual units yielded by the analytical procedures being used.

All of these possible differences make comparison of gas concentrations from the literature and from current investigations difficult, and often impossible because investigators have not reported exactly what they have measured. What appear to be anomalies in the data from any monitoring program may be the result of any combination of the above factors. Data from the NMFS program are extensive and intercomparable. In spite of some attempts to standardize methods, the analysts should clearly report their methods and actual measured concentrations so results can be compared with other work. It is apparent that there has been a lack of communication between the biologists and the oceanographers working on similar problems but for different purposes. A joint work conference between these two groups is necessary to develop standard methods for water sampling and gas analysis.

An approach to the supersaturation problem that would have much more merit from a physiological standpoint would be to measure the total partial pressure of dissolved gasses in the water. It is well established that all of the dissolved gasses are involved in the gas bubble disease phenomenon, and measurement of nitrogen concentration alone is not necessarily representative of the effect on fish.

A prototype device to measure total gas partial pressure *in situ* has been developed (Weiss, personal communication), however, until such a device is generally available, it will remain necessary to calculate the sum of partial pressures of nitrogen, oxygen, and argon from their measured concentrations and solubilities.

IV - BIOLOGICAL SOLUTIONS

The critical nature of the nitrogen supersaturation problem on the Columbia River has prompted drastic actions to somewhat relieve the demonstrated detrimental effects on the upstream and downstream migrating salmonids during the 1971 season. The mortality of juvenile migrants from the Snake River has been amply demonstrated and this fact alone dictates immediate action to salvage a portion of the downstream migration from the Snake River. An emergency meeting of the Northwest fishery agencies to consider the nitrogen problems was held in January, 1969 and resulted in formation of an ad hoc committee on nitrogen. A number of actions have been taken since that time by the fishery agencies and the Corps of Engineers.

Collection of Downstream Migrants

Experiments on the Snake River by the NMFS have shown that it is feasible to trap a portion of the downstream migrant chinook salmon and transport them by truck to the estuary for release, thereby greatly increasing their survival and not seriously imparing their homing ability as adults. The studies with marked juvenile spring and summer-run chinook in 1968 - 70 show a definitely increased survival from 1.5:1 before spill to 4.0:1 after spill due to transportation of the migrants from Ice Harbor to Bonneville (Ebel, 1970). A plan for experimental installation of traveling screens in one generating unit and the trapping plan at Little Goose Dam has been implemented for 1971 funded by the Corps of Engineers. The success of the program has been hampered by mechanical breakdowns. Full scale installation of screens at Little Goose will be based on the success of the 1971 program.

Adjustment of Hatchery Releases

The usual time of a release for most hatchery fish in the Lower Columbia River has been May and June, the period of maximum flow and maximum nitrogen levels. The Oregon Fish Commission trucked a large percentage of their juvenile fish in 1969 from hatcheries at or above Bonneville Dam and released them near Astoria in order to avoid this situation. In 1970, an attempt was made by all agencies to release at least some of the fish at the hatcheries before nitrogen levels become too high. However, an unexpected and early increase in the river flow made it necessary to release most of the hatchery production of all fishery agencies into water of relatively high levels of nitrogen. In order to avoid this problem in 1971 and make the best possible conditions for the release of hatchery fingerlings, a closely coordinated plan between the Corps of Engineers and other power producers and the fishery agencies was developed. This was accomplished through the efforts of an interagency task force that met bi-monthly during the spring of 1971. Careful advance planning on the part of the fishery agencies, the Corps of Engineers and Bonneville Power Administration was necessary in order to implement this plan. A mass release of 40 million fall chinook fingerlings by the several fishery agencies was made on April 26 and 27, during a period that the flow at Bonneville Dam was held to 180,000 to 200,000 cubic feet per second. This flow minimized the spill at Bonneville Dam and eliminated spill at all other mainstem dams on the Columbia. Spill at the three lower Snake River dams was reduced during this period. Nitrogen conditions below Bonneville Dam were minimized during this five-day period of reduced flows and indications are that the fish moved out as expected.

A release of steelhead fingerlings from Dworshak hatchery on the Clearwater River in early April failed to produce the desired results probably due to cold water and small size of the fish which delayed migration.

The wild fish emigrating from the upper Columbia and the Snake River will receive only limited benefits from the controlled release plan as they characteristically move on the highest flows which is also the period of the highest nitrogen concentrations.

Future of Up-River Fish Runs

There is considerable pessimism over the current nitrogen problem and its effects on migrating salmon into the Upper Columbia and Snake Rivers. If the studies of the NMFS on the Snake River accurately portray the fate of wild migrants from that area and current efforts to alleviate the problem are only partially successful, the Snake and upper Columbia runs could be greatly reduced within a three-year period. The runs of fall chinook salmon above Priest Rapids Dam are already in jeopardy because of the failure of artificial propagation facilities (spawning channels) in that reach of the river (Meekin, 1971). Dams and reservoirs have converted the Columbia River from a flowing stream into a series of lakes (with exception of the Hanford reach) which retard the out-migration of juvenile salmonids to the ocean and thereby subject them to increased stresses including temperature, diseases, predation, and high nitrogen levels. The fate of juvenile migrants from the sizeable fall chinook population spawning in the Hanford Reservation below Priest Rapids is unknown.

Mortalities to juvenile salmon and steelhead passing through the turbines of dams is well known. Better control of discharge by increased upstream storage and passage of more water through the turbines will aggravate this already serious problem. The only hope to reduce mortalities from this source is implementation of the fish screening and trapping program that has been initiated on the Snake River.

If a major percentage of the juvenile migrants arriving at Little Goose Dam on the Snake River can be successfully trapped and transported to the lower Columbia River, they can be protected both from the high nitrogen and high mortality from passage through turbines. The high natural potential for producing these fish remains in the Salmon River where no dam development has taken place and in several other smaller tributaries to the Snake River.

In summary, as long as unacceptable nitrogen levels (105 percent) exist and high turbine mortalities occur, it seems the only reasonable way to salvage a portion of the Snake River salmon and steelhead runs is by trapping the juvenile migrants and hauling them around the area of high nitrogen from Little Goose Dam to below Bonneville. An accelerated schedule for installation of the trapping facilities will be necessary to accomplish this. The future of runs on the mainstem Columbia above the Snake River is less certain. Collection of migrants at McNary Dam would help to maintain those runs as well as collect the residual from the Snake River. Implementation of all controls for nitrogen will help relieve exposure of migrants from tributaries below McNary as well as give considerable protection to adult upstream migrants.

V - ENGINEERING SOLUTIONS

Introduction

Purpose and Scope

The purpose of this chapter is to present and discuss engineering solutions to the nitrogen problem in the Columbia and Snake Rivers. Since excessive nitrogen supersaturation in the river appears to be directly related to the quantity of flow (usually flood flows) passing over the spillways of dams and plunging into deep stilling basins (see Figures 6 and 7), this chapter will deal primarily with the causes and effects of these spills and will discuss proposed methods of reducing them. The magnitude and duration of spills expected in the existing system of dams and reservoirs in the Columbia and Snake Rivers will be examined under varying hydrologic and operational conditions. Conditions expected to develop in the future will also be analyzed.

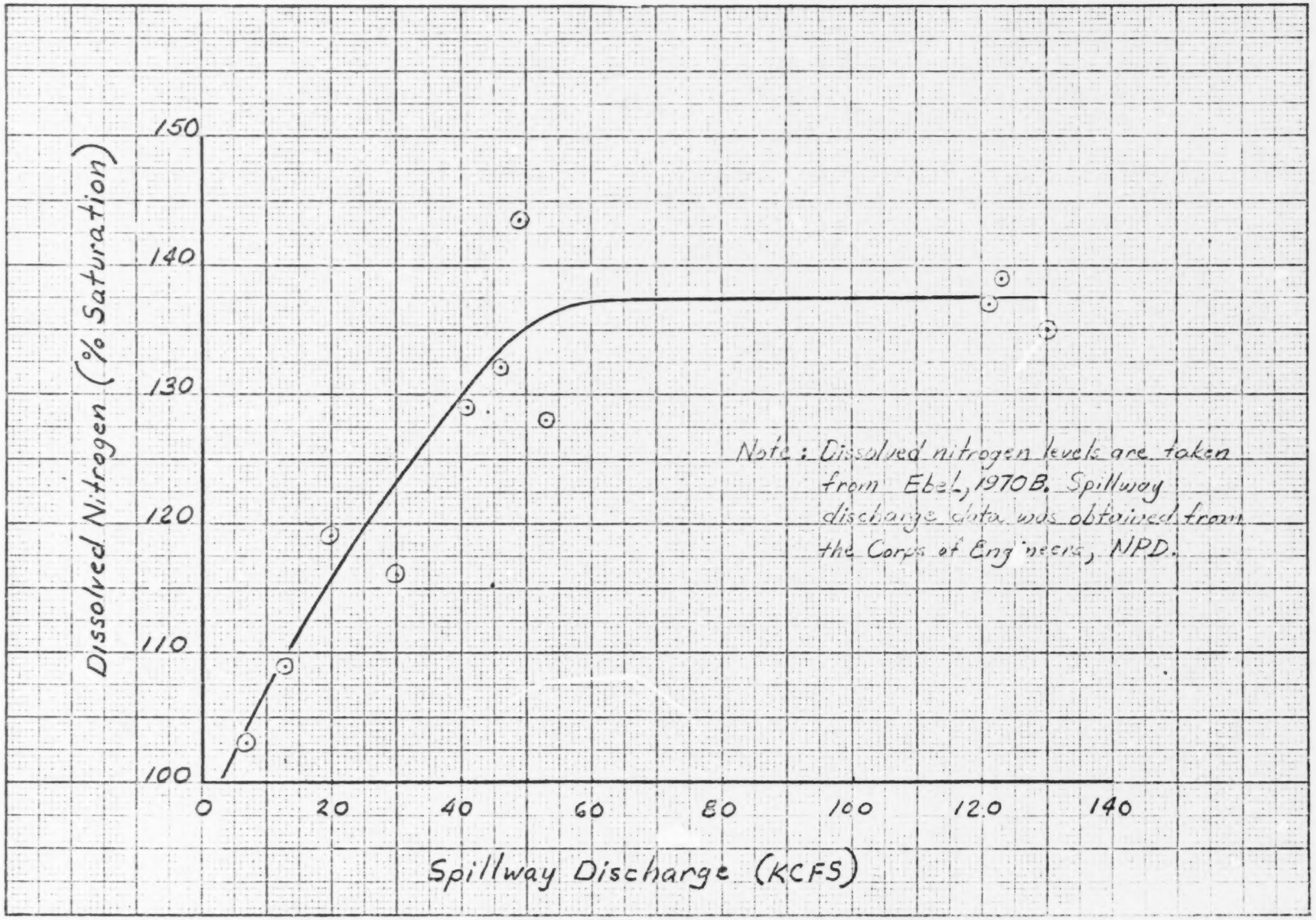
Conceivably there will be solutions to the nitrogen problem which would be physically possible but, because of operational or legal restrictions, would be unavailable for actual implementation. These constraints to solving the problem will be identified and the problems in removing these restrictions will be discussed.

As demands for power and water continue to grow in this region, power generating facilities will have to be expanded and reservoir regulation operations will have to be modified. The effects of this expansion and modification on the nitrogen problem will be discussed.

Finally, recommendations for engineering solutions will be made, and needs for further study of some problems and potential solutions will be identified.

Methodology

Several basic assumptions are necessary to an analysis of engineering aspects of the nitrogen problem. As stated in Anonymous, 1971C, these are as follows:



Note: Dissolved nitrogen levels are taken from Ebel, 1970B. Spillway discharge data was obtained from the Corps of Engineers, NPD.

Figure 6 Dissolved Nitrogen Relationship--Lower Snake River (Little Goose Project)

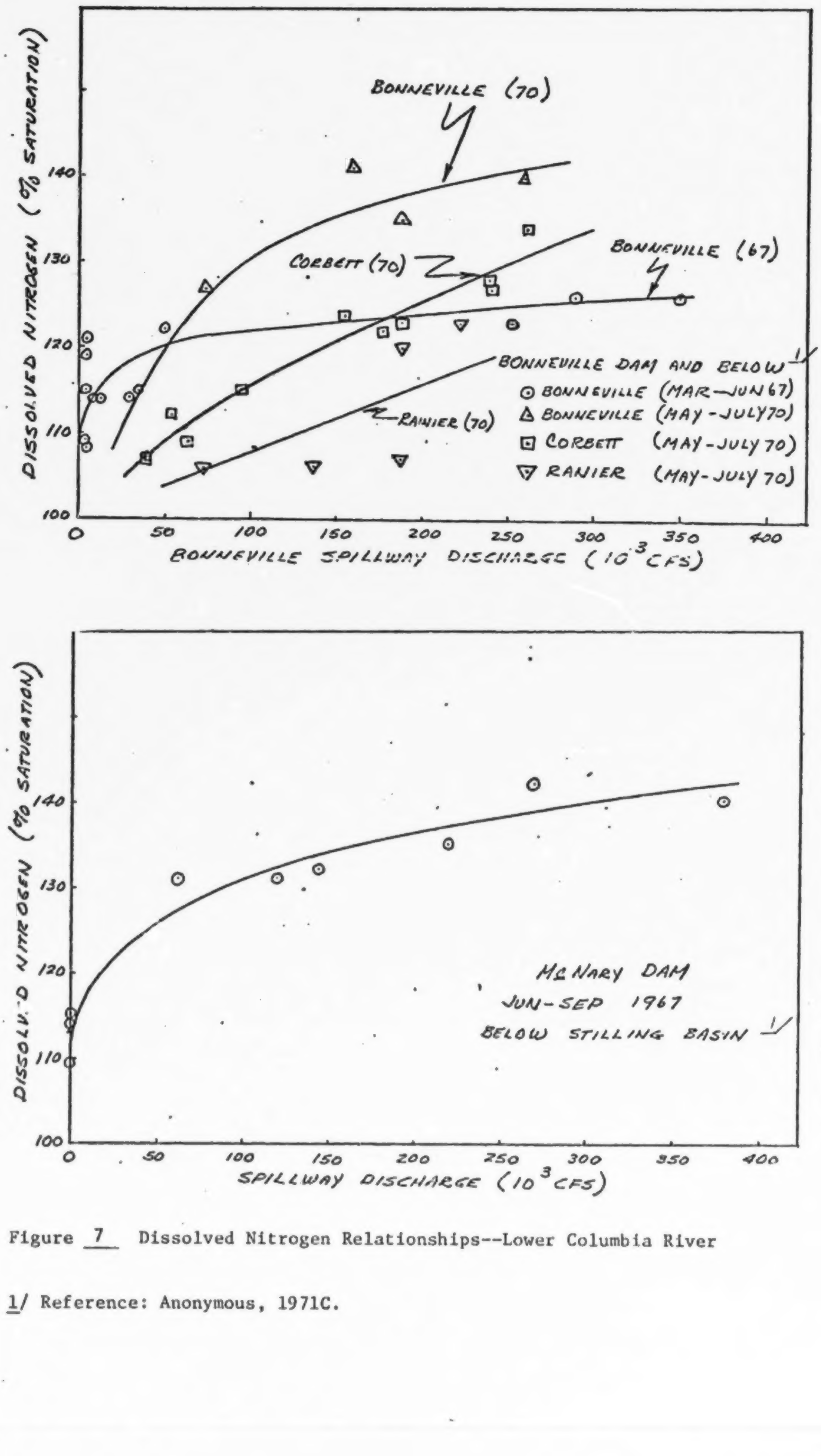


Figure 7 Dissolved Nitrogen Relationships--Lower Columbia River

1/ Reference: Anonymous, 1971C.

"A. The spillway-stilling basin structure, the release area for river flow surplus to that required by the turbine-driven generators of the powerhouse, is the location where the nitrogen supersaturation originates.

B. Flow released through the power plant does not appear to increase the saturation level of the incoming flow to the project.

C. The output nitrogen supersaturation level downstream from most spillways generally increases as the flow increases -- possibly up to a certain level and then remains about the same.

D. There is some indication that the deeper stilling basins are more "efficient" in supersaturating the project outflow."

To provide a framework for an engineering study of the nitrogen problem, a "base condition is first described and analyzed. This "base condition" consists of the existing dams and reservoirs and those under construction (see map, Figure 1), existing power facilities and those expected in the future, and normal operating procedures which would be followed if no particular consideration were given to solution of the nitrogen problem. Using computer studies of reservoir regulation and power generating operations prepared by the Corps of Engineers and the Bonneville Power Administration, the characteristics of spills expected under the "base condition" and during the normal flood season of low, average, and high water years were analyzed for various locations in the Columbia and Snake Rivers.

The computer studies used in the analysis are based on historical hydrologic data, synthesized from actual flow records of past years and adapted to account for the present and future regulation of the rivers by the existing and future system of dams and reservoirs. Based on the hypothetical unregulated volume of runoff at The Dalles, Oregon, occurring during the flood season (April through August), the year 1956 was selected as a year with relatively high flows, the year 1952 was selected as an average water year and 1944 was selected as a relatively low flow year. Flows comparable to the 1956 flood have a statistical probability of being equalled or exceeded roughly once in ten years. Average flows, comparable to those in 1952, would be equalled or exceeded once in two years. Low flow conditions (1944) have a probability of being equalled or exceeded of 95 percent; or, only one year in twenty would lower flow be expected. Although the 1956 flood has a statistical probability of being exceeded fairly often (once every ten years), it is still a flood of high magnitude, its volume being the largest recorded at The Dalles since 1900 (see Figure 8).

After a past year was selected as having a given frequency of recurrence (based on flows at The Dalles), hydrographs of flows at the other stations in the Columbia and Snake Rivers were tabulated and graphed for that same year and assumed to have roughly the same frequency. This introduces a possible source of error in the method, because flows at The Dalles in a certain past year may have a different frequency than the flows at another station for the same year. In fact, frequency analyses of historical flows on the lower Snake River revealed that flows in the year 1932 were actually much more representative of average conditions than the 1952 flows which were selected as average for the Columbia River. For this reason, 1932 flows are presented in this report as average for the lower Snake rather than 1952. The method of analysis must be assumed approximate, but is considered adequate for this presentation.

In the second phase of the study an analysis was made of the effect on the base condition of various proposed methods of controlling nitrogen. The solutions studied fell into three general categories. The first were operational types of modifications to reservoir regulation and power operations. The second broad category consisted of solutions requiring structural types of modifications, and the third group consisted of combinations of operational and structural modifications. All the solutions studied in this phase were considered available for implementation, providing capital and operational costs could be funded. Legal restrictions on the measures could not be discerned.

The third phase of the study consisted of an analysis of some types of solutions which were considered physically possible, but involved some significant legal or operational restrictions. In this phase of the study, it was first assumed that the only limitations on the solutions would be physical; that is, there would be no legal or operational considerations involved. The effects in reducing spills were then measured. After this was done, the constraints that had to be removed to implement this set of solutions were examined to determine the problems and costs involved.

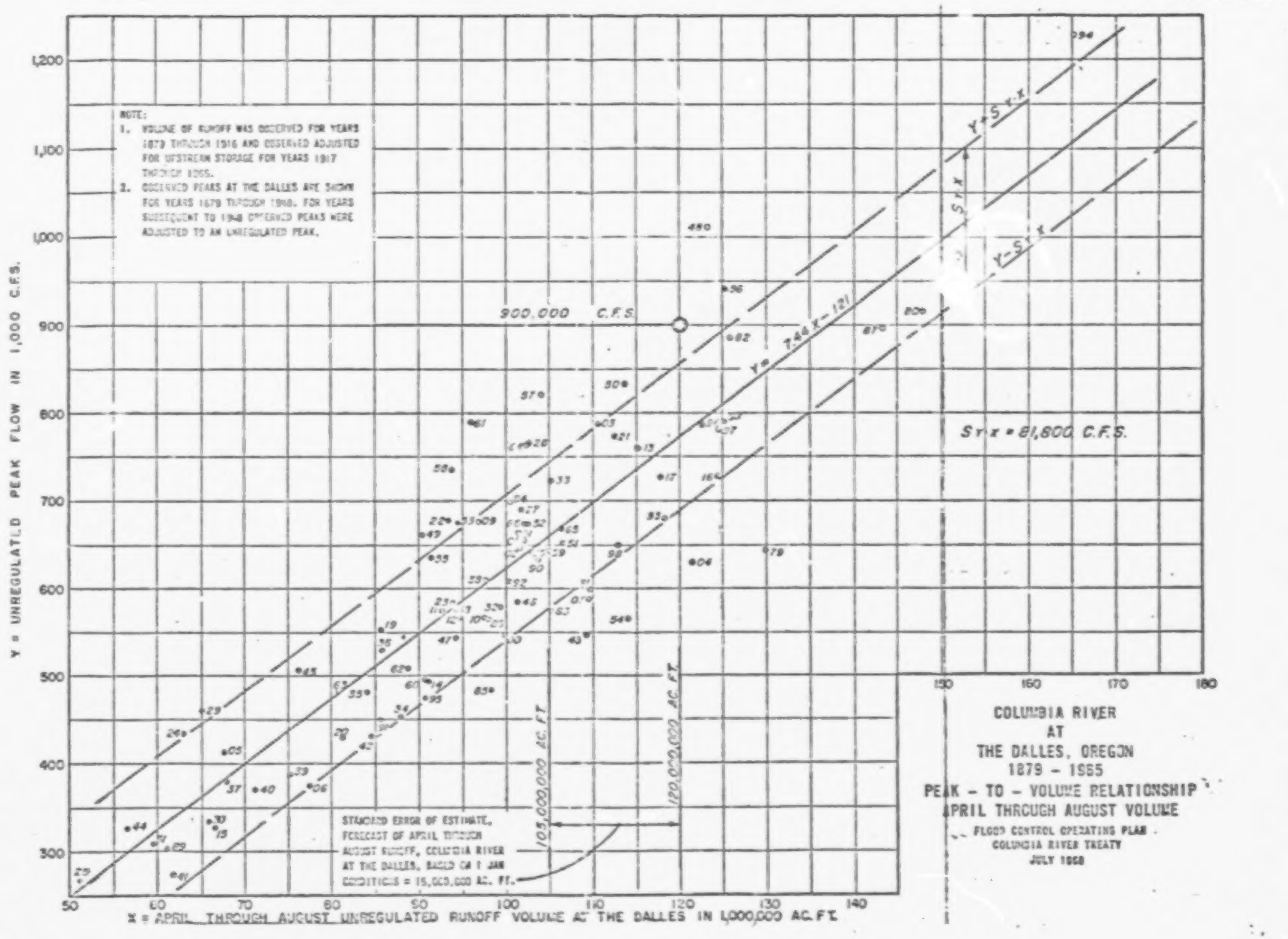


Figure 8 Unregulated Flow at The Dalles, Oregon

1/ Reference: Anonymous, 1968.

Because of time limitation the analyses described in this section were based almost exclusively on data and computer studies already on hand and usually prepared for other purposes. No attempt was made to perform additional studies specifically tailored for nitrogen considerations. Consequently, information had to be drawn from several sources, with some sacrifice in the continuity of certain presentations.

Analysis of the "Base Condition"

Definition of Base Condition

Problems related to nitrogen supersaturation have been noted in many streams throughout the Columbia-North Pacific Region. However, for this study primary emphasis was placed on the main stem Columbia and lower Snake Rivers. The stream reaches selected for detailed study were: the main stem Columbia River from its mouth to Grand Coulee Dam, at river mile 596.6; and the Snake River from its confluence with the Columbia River up to Lower Granite Dam, at river mile 107.5. Although some information was collected on all the dams in the reaches listed above, due to the limited scope of the study and time limitations involved, certain dams and reservoirs were selected for detailed presentations of hydrology and power operations. Problems at other selected dams in the Columbia-North Pacific Region were also noted, however, and will be mentioned.

Average daily flows obtained from Corps of Engineers' computer studies were tabulated and graphed for two control points on the main stem Columbia River -- Priest Rapids and John Day dams -- and for one point on the lower Snake River -- Clarkston, Washington. These graphs were constructed for the conditions existing as of 1970, and for conditions expected in 1980, and used with predicted flows through hydroelectric turbines to predict spillway discharge. Each case was examined for effects in high, average, and low water years corresponding to historical flows in the years 1956, 1952, and 1944 respectively. Some 19 million acre-feet of active storage in three new reservoirs -- Libby, Mica, and Dworshak -- will soon be available for river regulation, and the predicted 1980 conditions reflect the proposed use of this additional storage. Libby Reservoir is presently in the process of filling, Dworshak is scheduled to begin filling in 1972, and Mica is to begin filling in 1973. By 1975 all three should be operational.

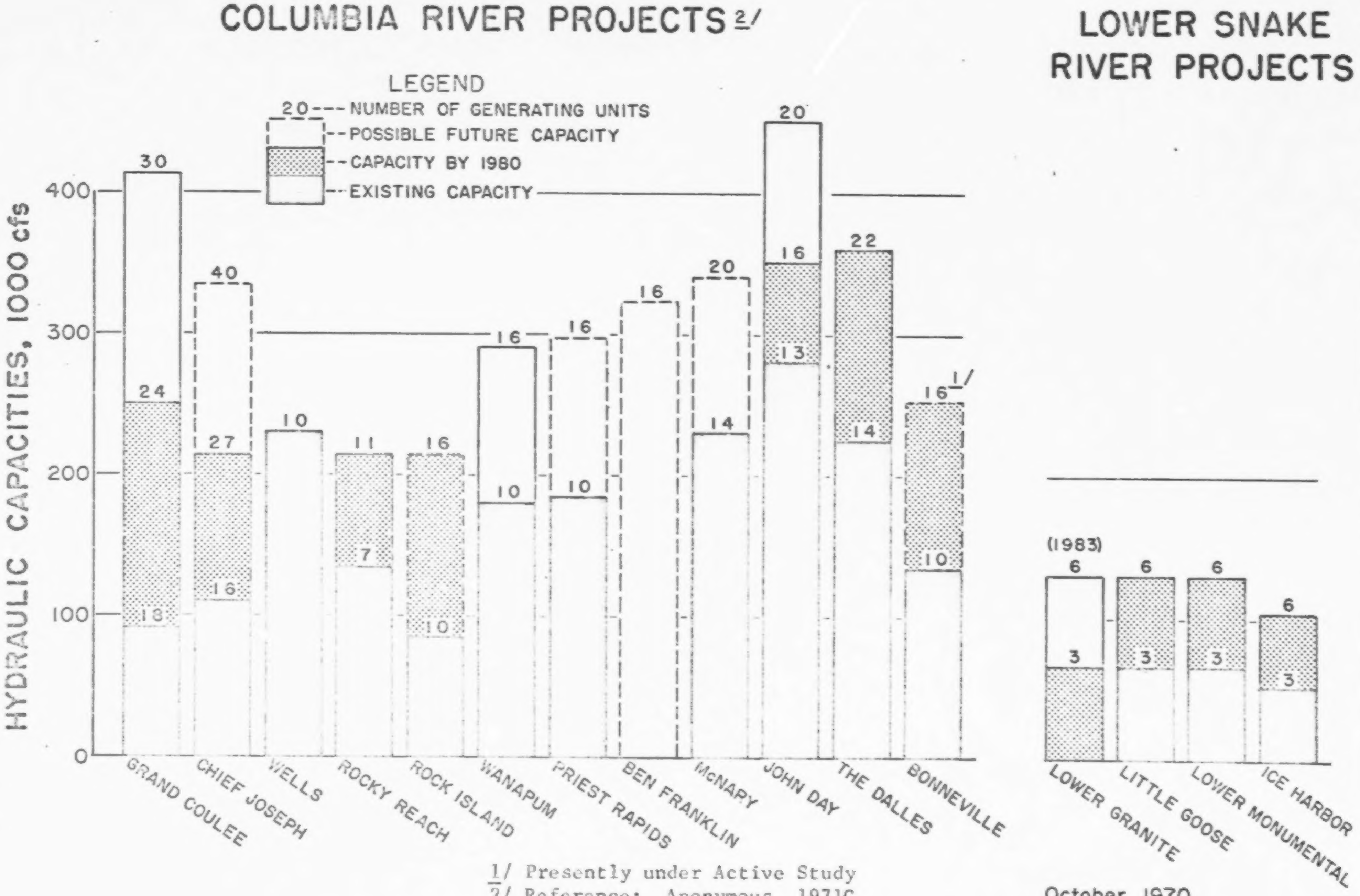
The projects included in this study and their hydraulic capacities are shown on Figure 9. The dams shown are all federally owned and operated except for five located in the Mid-Columbia River reaches. These five -- Wells, Rocky Reach, Rock Island, Wanapum, and Priest Rapids -- are owned by several public utility districts located in the State of Washington. Although the projects listed were the ones selected for analysis in this study, the entire system of dams and reservoirs on the Columbia and Snake Rivers and their tributaries was included in the computer studies used for predicting the flows at various points.

Figure 10 presents hydrographs of flows during the flood season (April through July) at selected projects in the Columbia-Snake River system, and expected flows through the turbine-generator units at each project under the "base condition." Any flows above those required for power generation are assumed to pass over the spillways.

One set of data (Figure 10a) presents the situation as of 1970; the other set (Figure 10b) shows the situation expected in the year 1980 when additional river regulation is available from upstream storage in the new Libby, Mica, and Dworshak Reservoirs. No other significant storage will be constructed before 1980. Therefore, the hydrographs of the 1980 situation represent conditions from about 1975 (when the three new reservoirs are operational) to 1980. On the other hand, in response to an increasing demand for electric power in the region, the loads carried by the power facilities at the dams will also increase. As the system loads increase, more generating units will be added, more flow will be passed through turbines and less therefore over the spillways. It is anticipated, then, that average spillway flows will continue to decrease up to 1980. Power peaking (discussed later) will be increasing, however, and this may cause the daily peak spills to increase through the period.

Given the present hydraulic design of the turbine units in the Columbia system, it is not practical to allow them to pass water without generating power. The power units in the Columbia and Snake systems are designed to operate best when they are generating about 80 percent of their total capacity. Running flow through these units with low loads produces

NOT REPRODUCIBLE



1/ Presently under Active Study
2/ Reference: Anonymous, 1971C

October 1970

Figure 9 Hydraulic Capacity of Generating Units

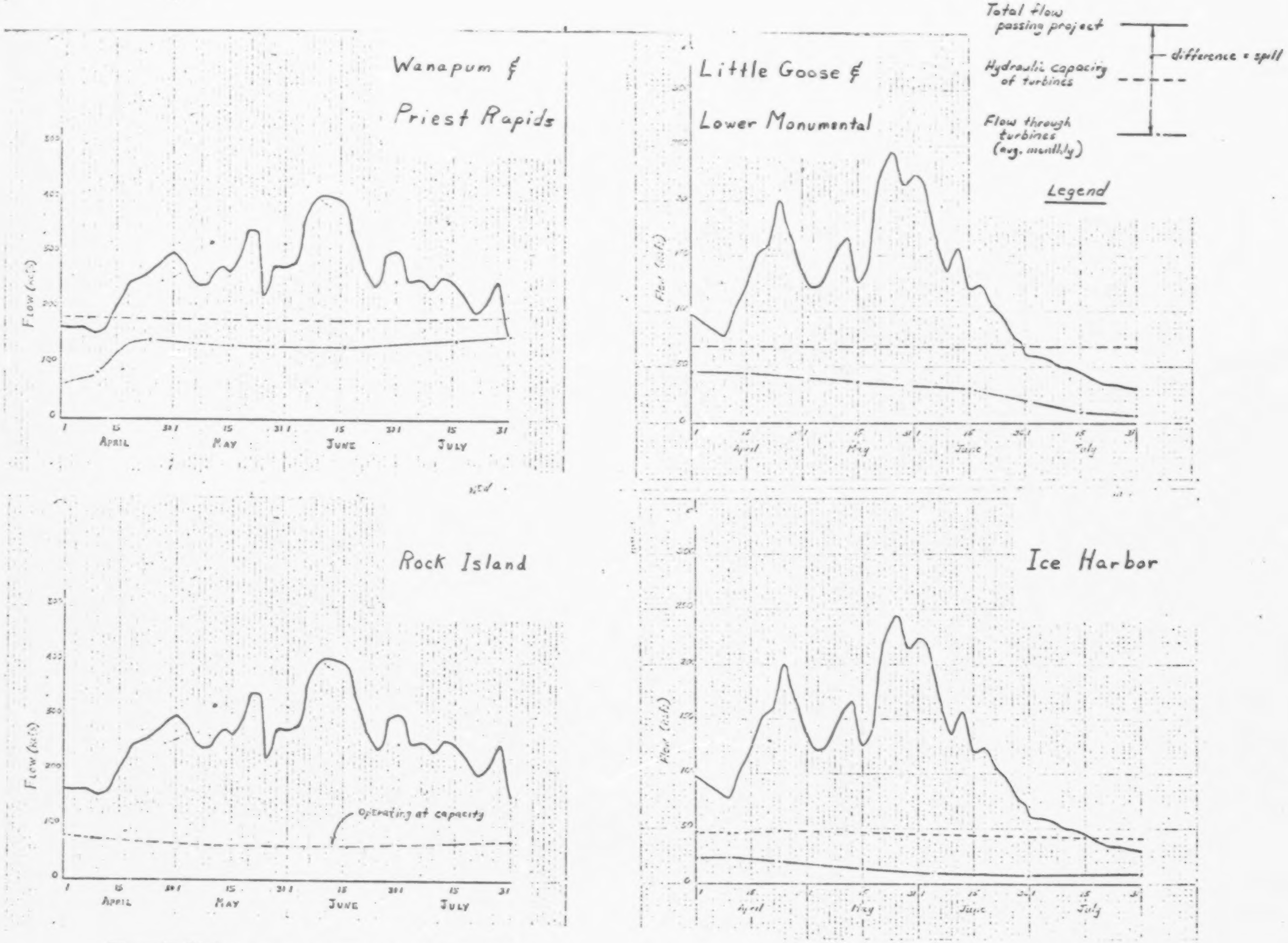


Figure 10a(1) Base Condition, 1970, High Flow Year (1956)

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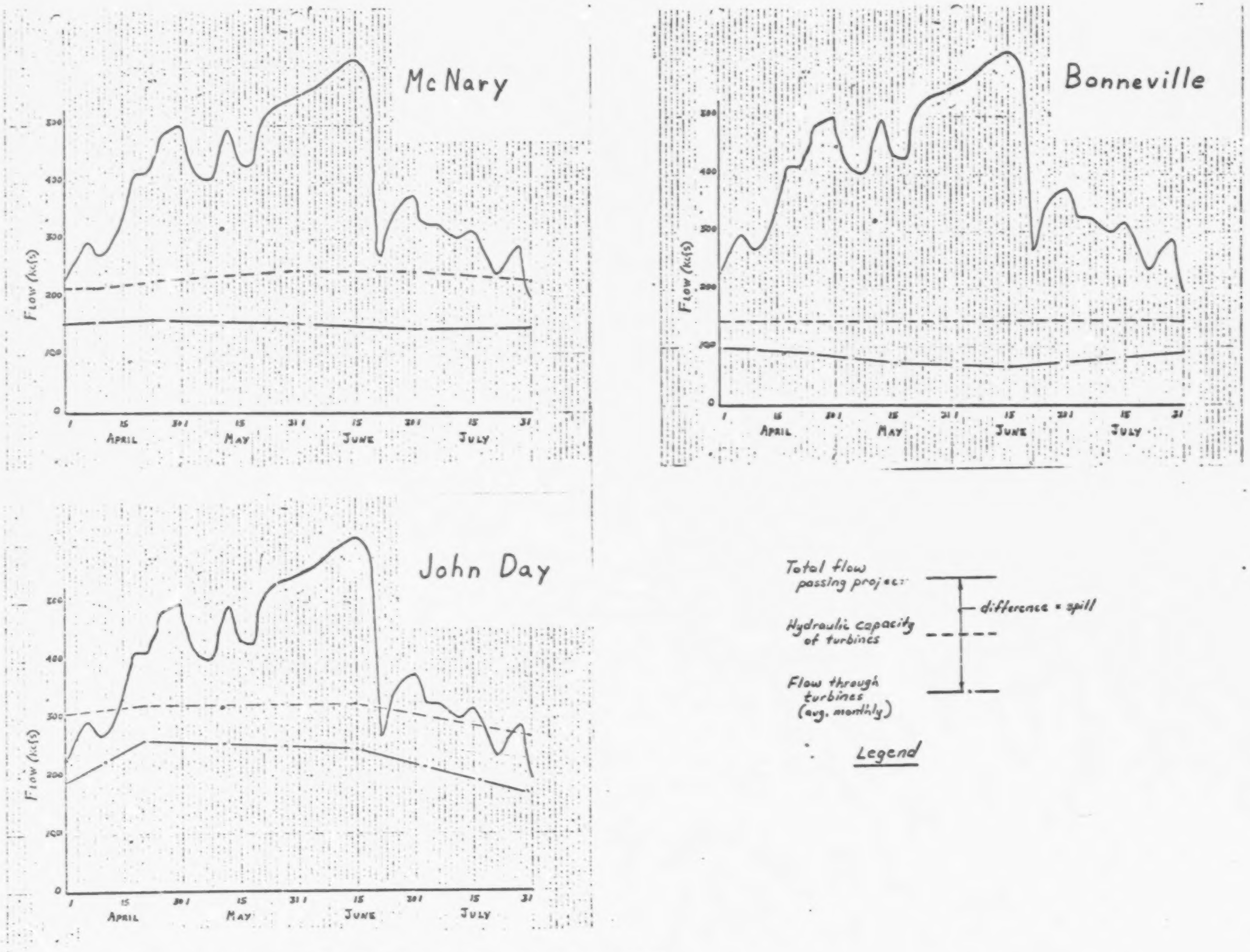

Figure 10a(1) [Continued] Base Condition, 1970, High Flow Year (1956)

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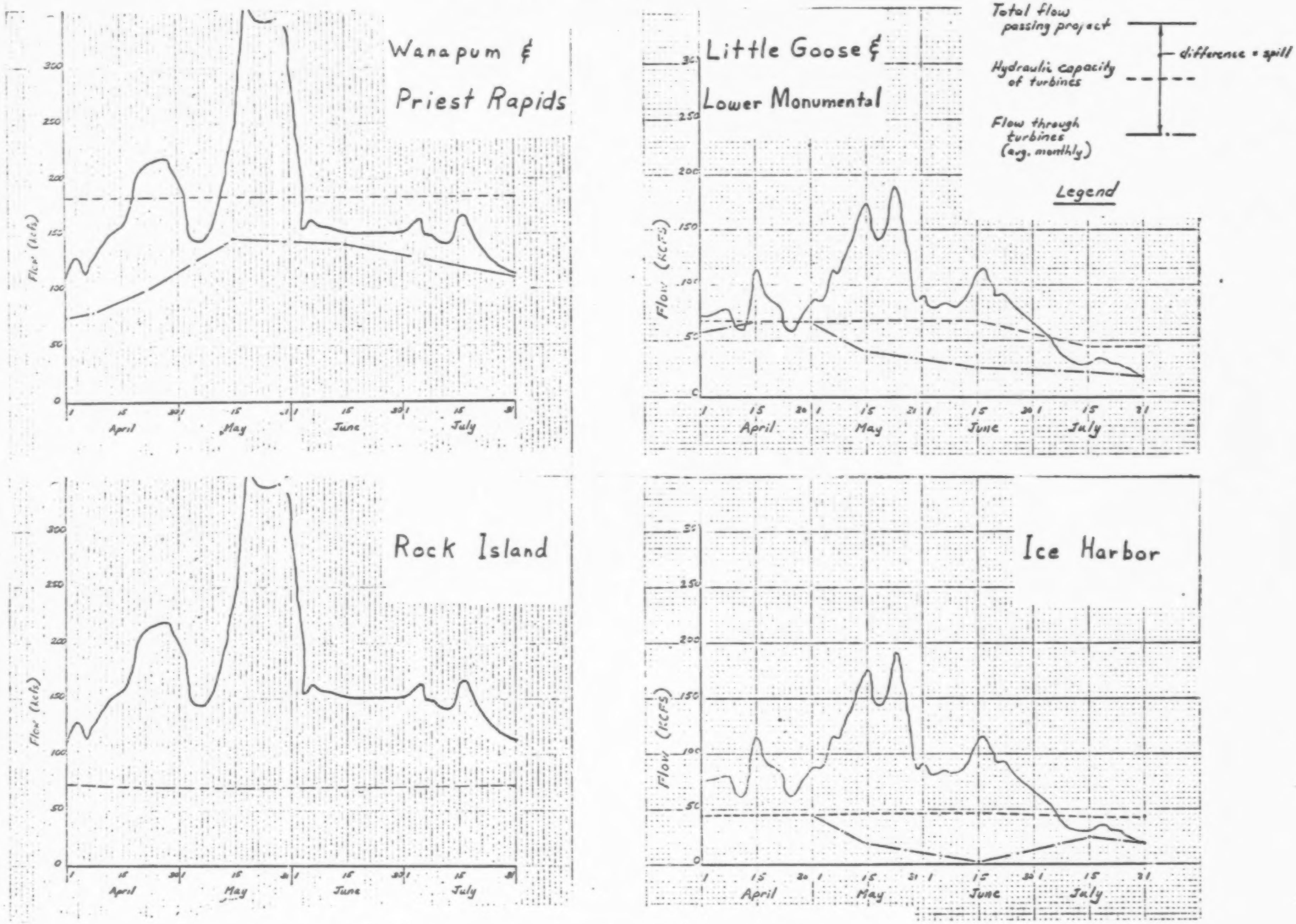

Figure 10a(2) Base Condition, 1970, Average Flow Year (Columbia-1952, Snake-1932)

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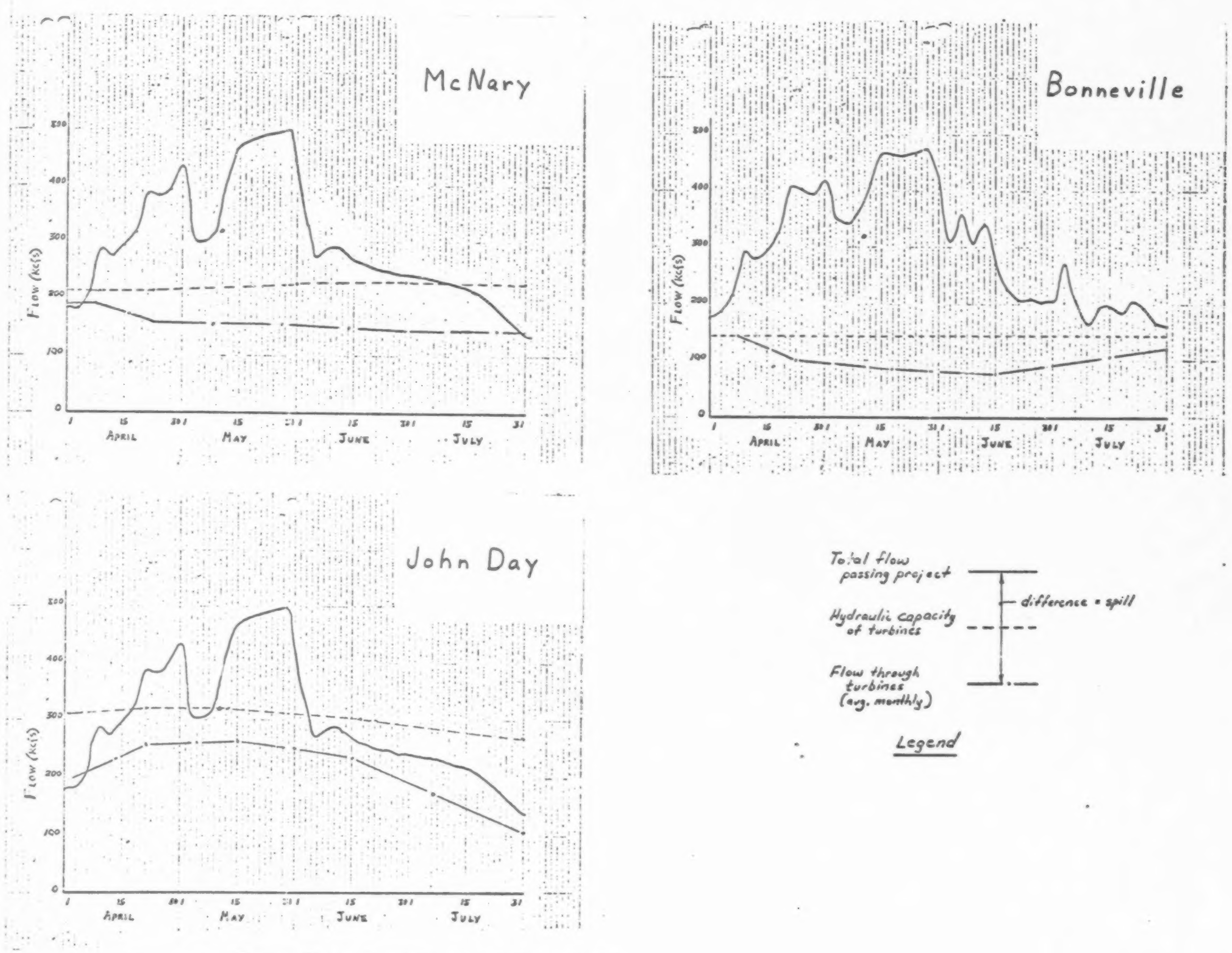

Figure 10a(2) [Continued] Base Condition, 1970, Average Flow Year
(Columbia-1952, Snake-1932)

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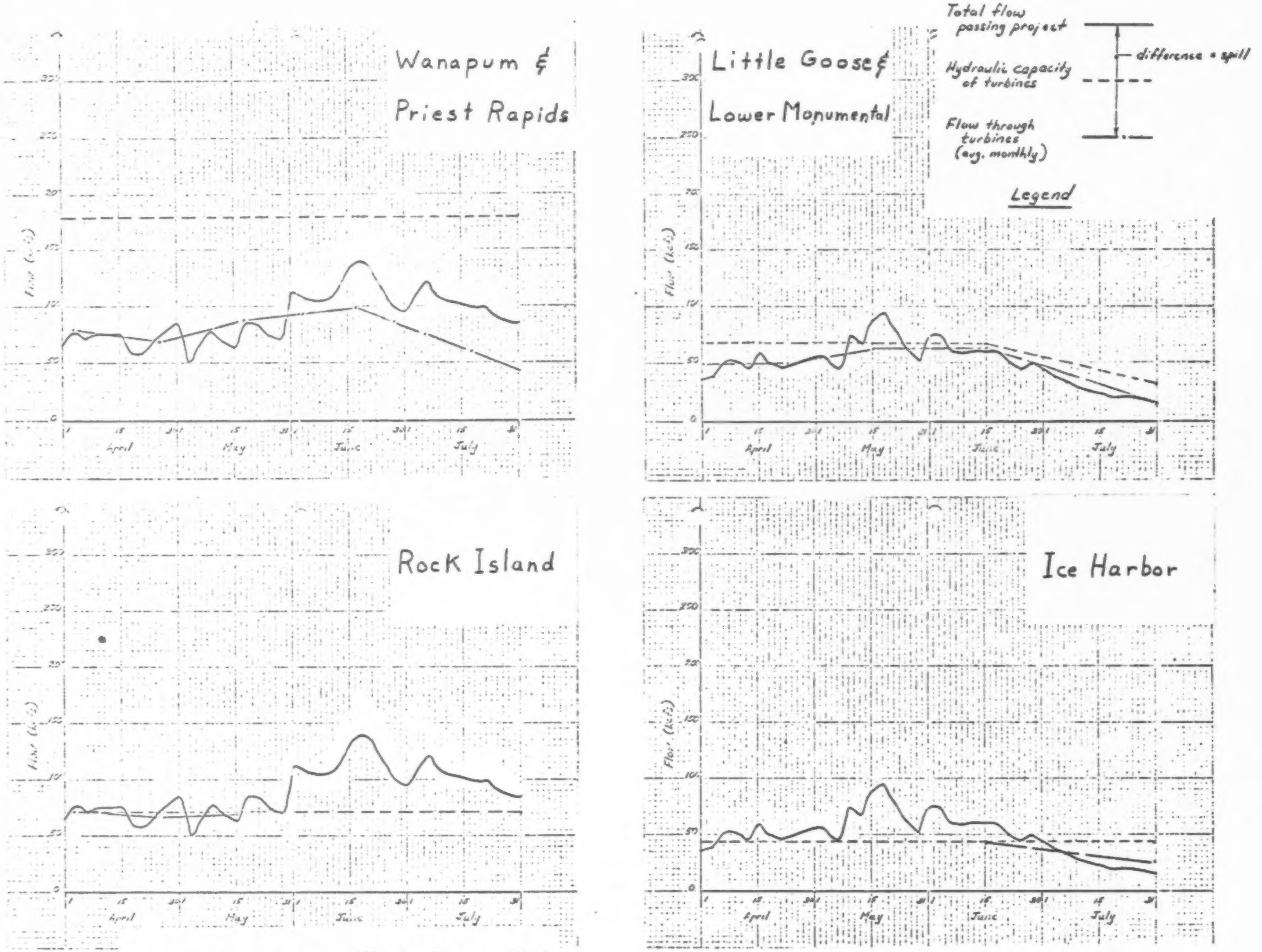

Figure 10a(3) Base Condition, 1970, Low Flow Year (1944)

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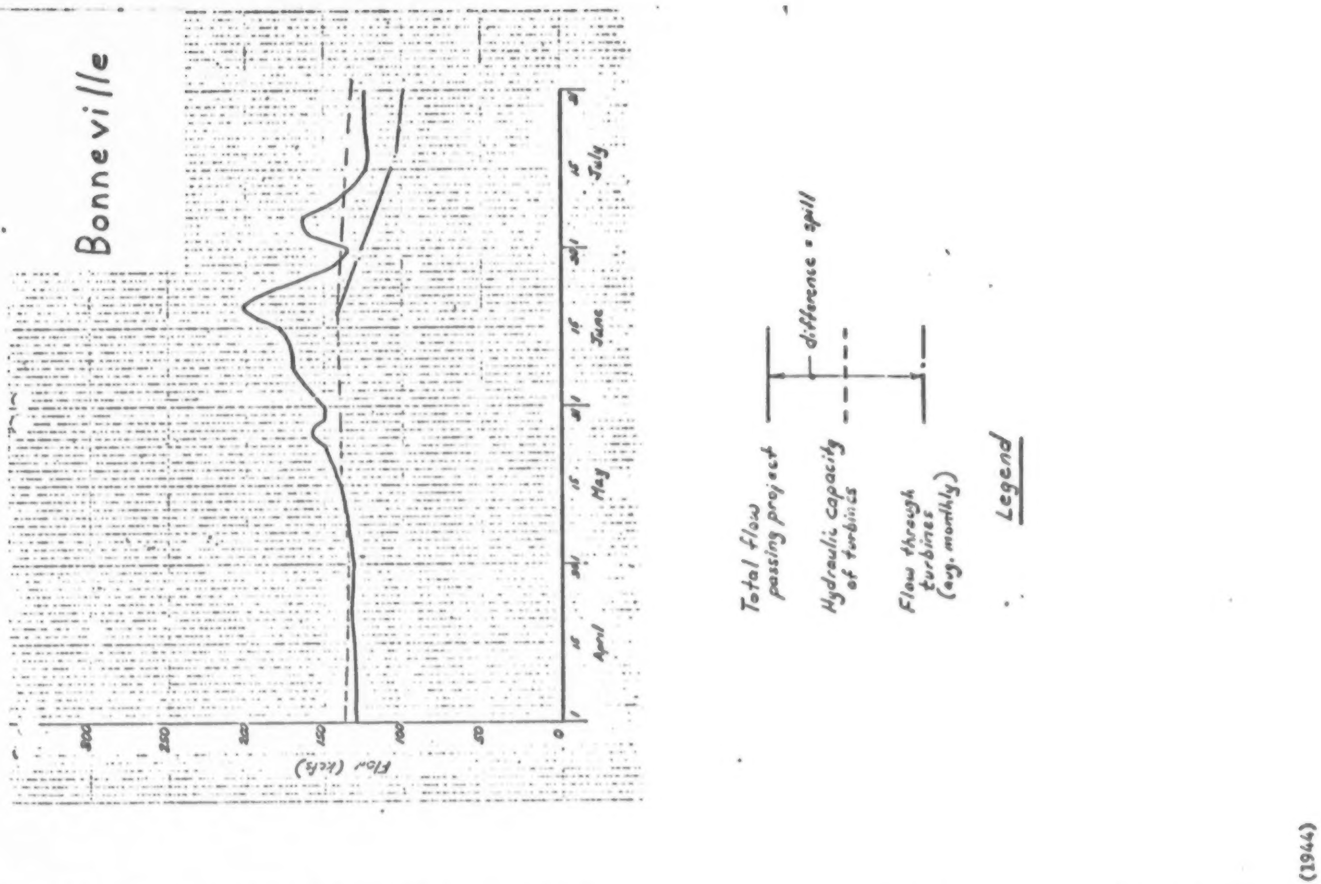

Figure 30a(3) [Continued] Base Condition, 1970, Low Flow Year (1944)

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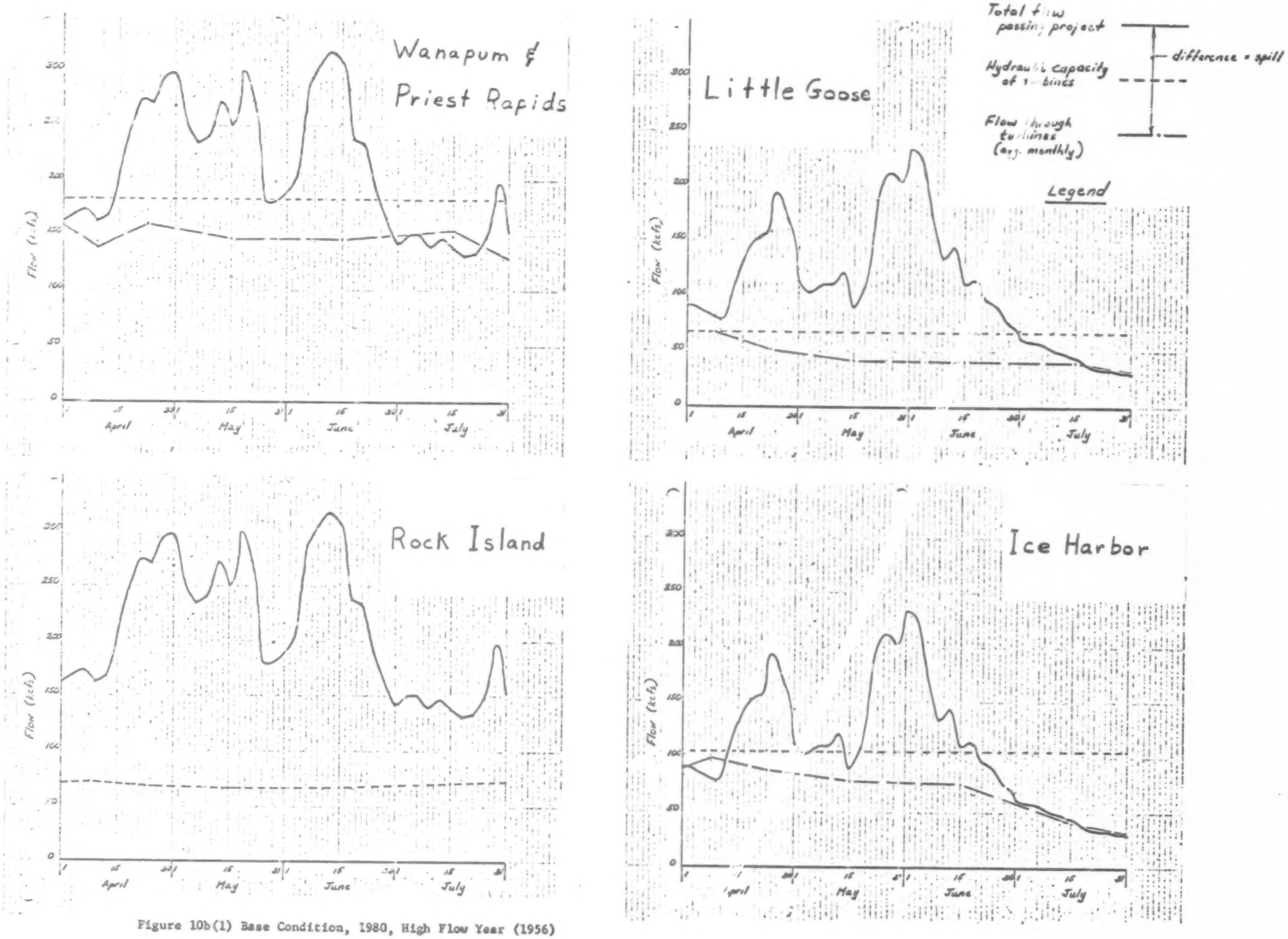

Figure 10b(1) Base Condition, 1980, High Flow Year (1956)

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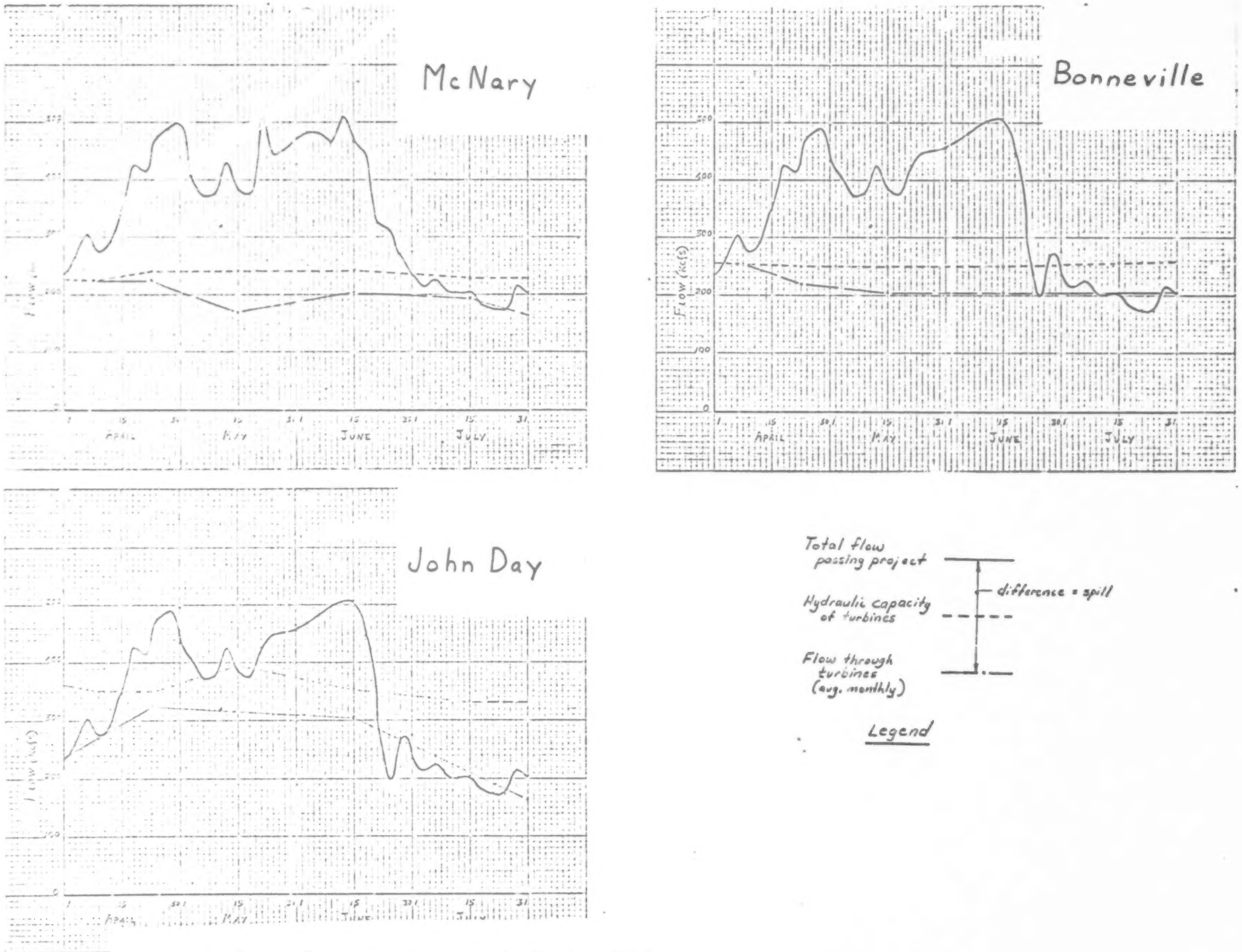

Figure 10b(1) [Continued] Base Condition, 1980, High Flow Year (1956)

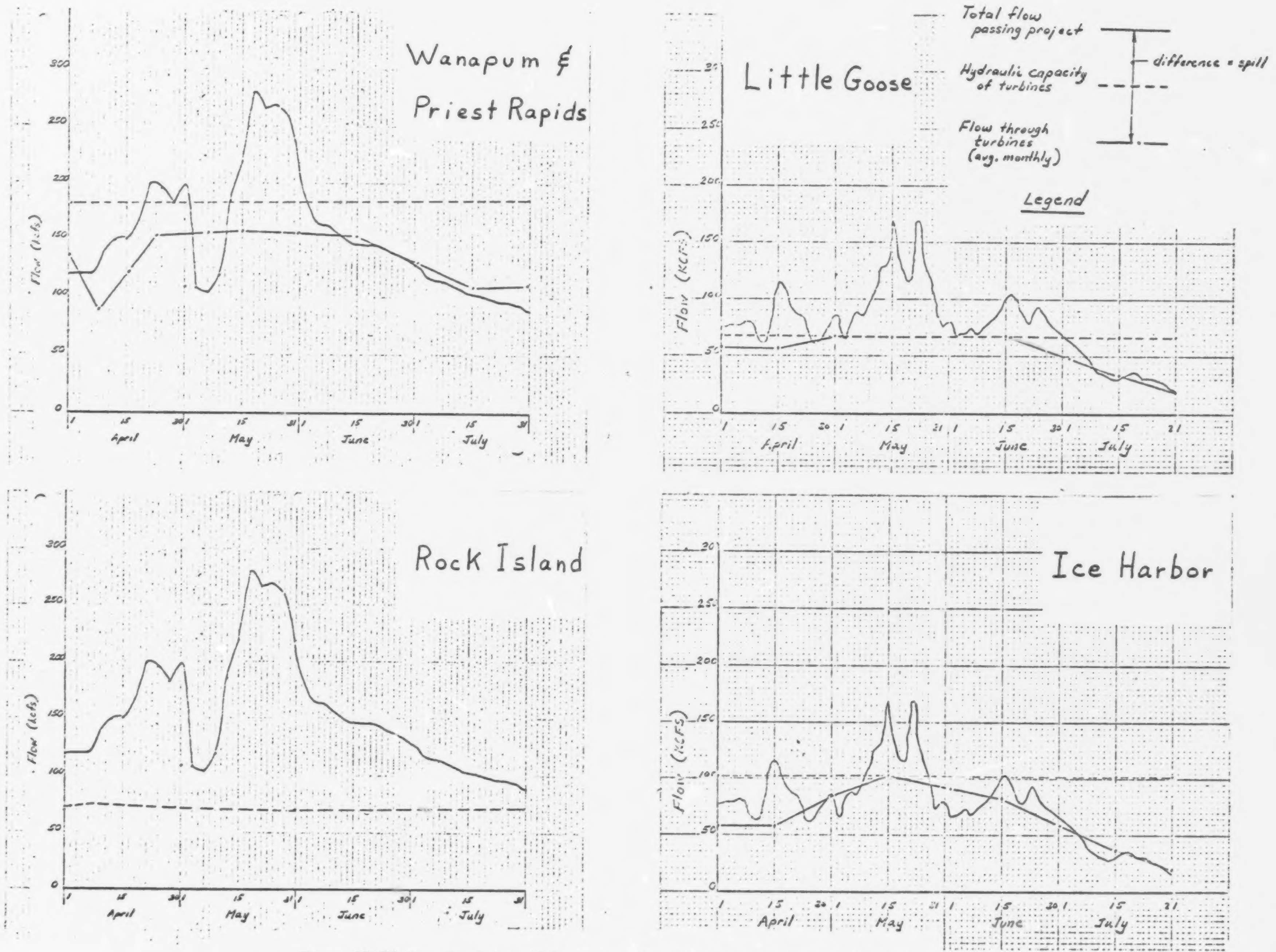

Figure 10b(2) Base Condition, 1980, Average Flow Year (Columbia-1952, Snake-1932)

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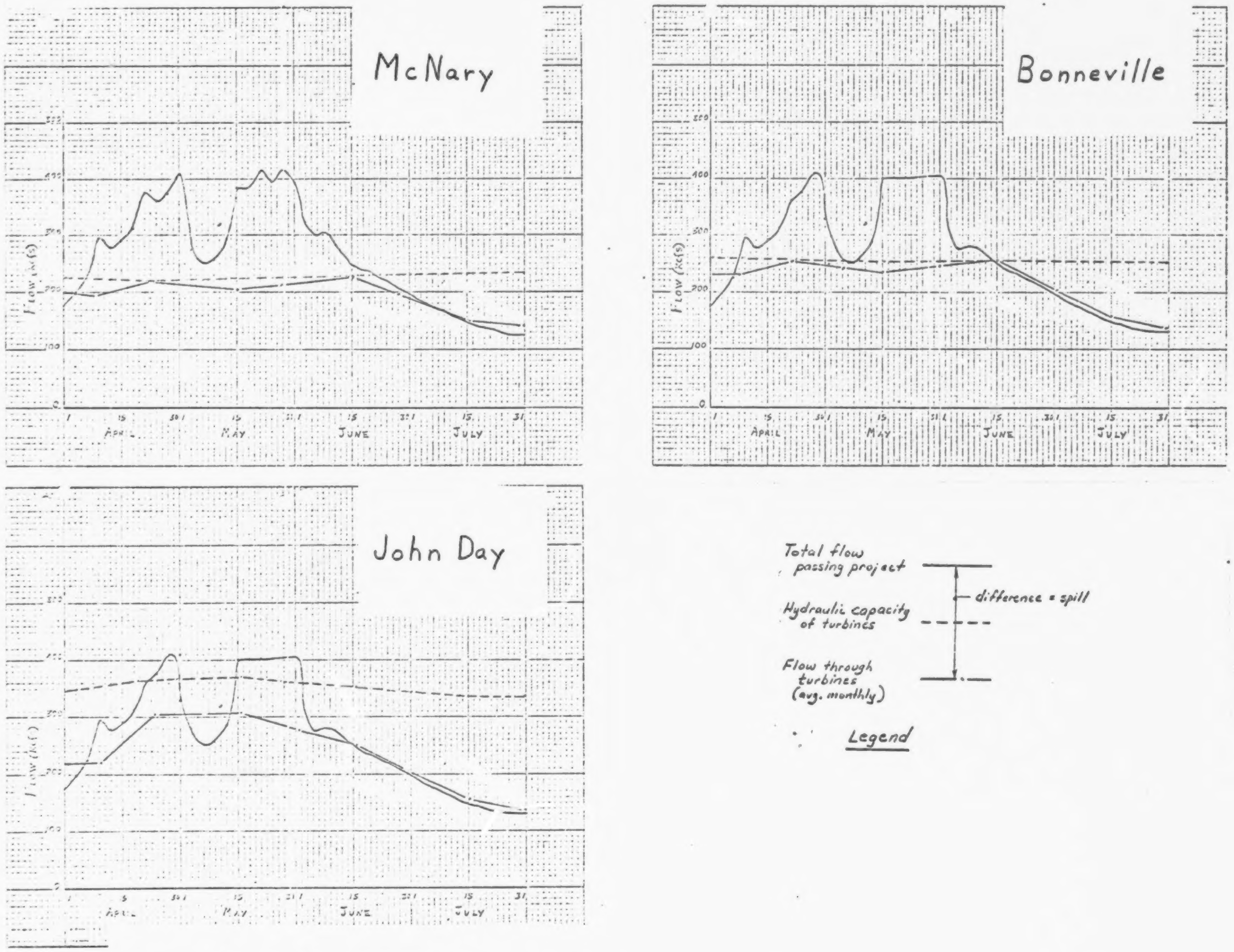

Figure 10b(2) [Continued] Base Condition, 1980, Average Flow Year (Columbia-1952, Snake-1932)

NOT REPRODUCIBLE

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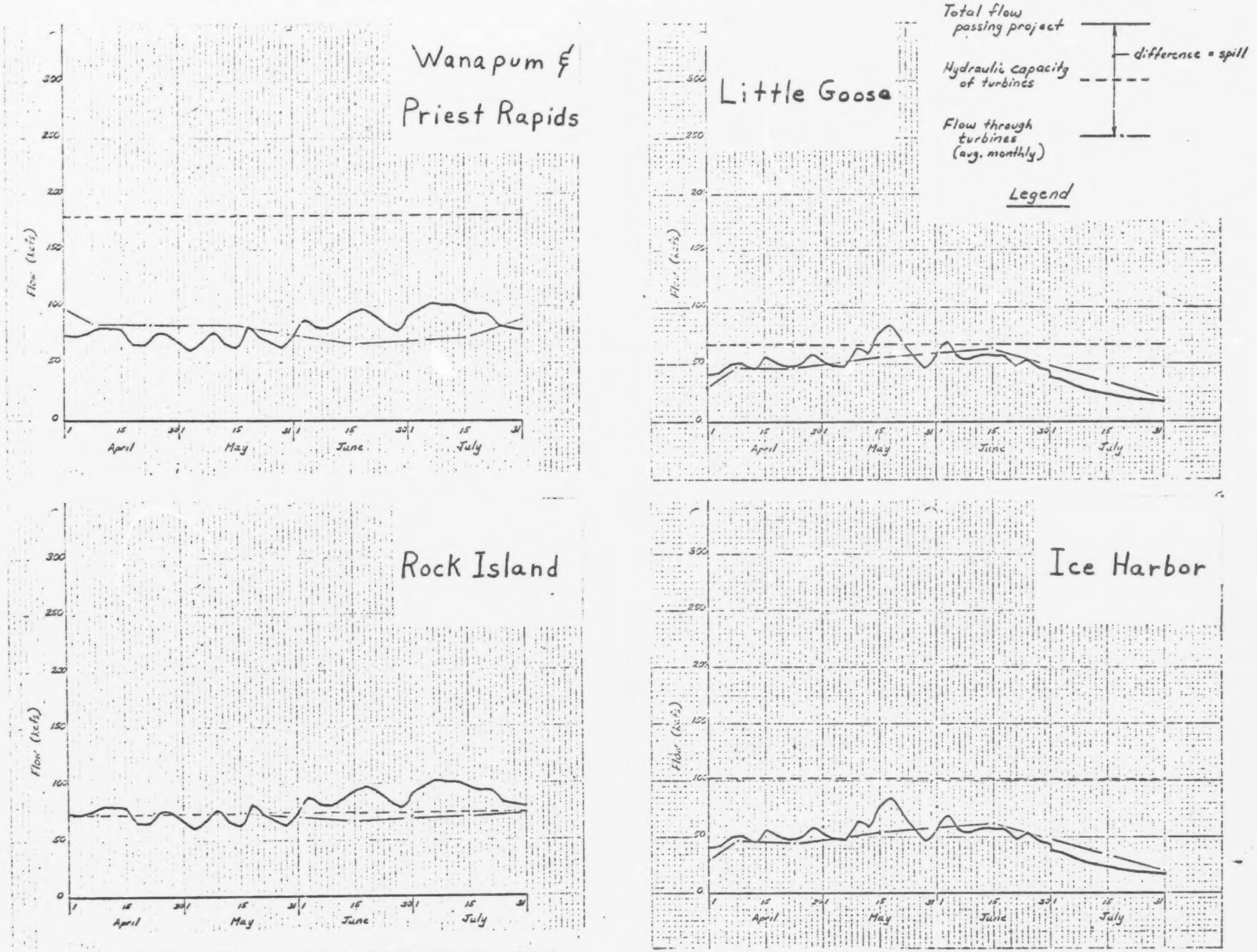

Figure 10b(3) Base Condition, 1980, Low Flow Year (1944)

NOT REPRODUCIBLE

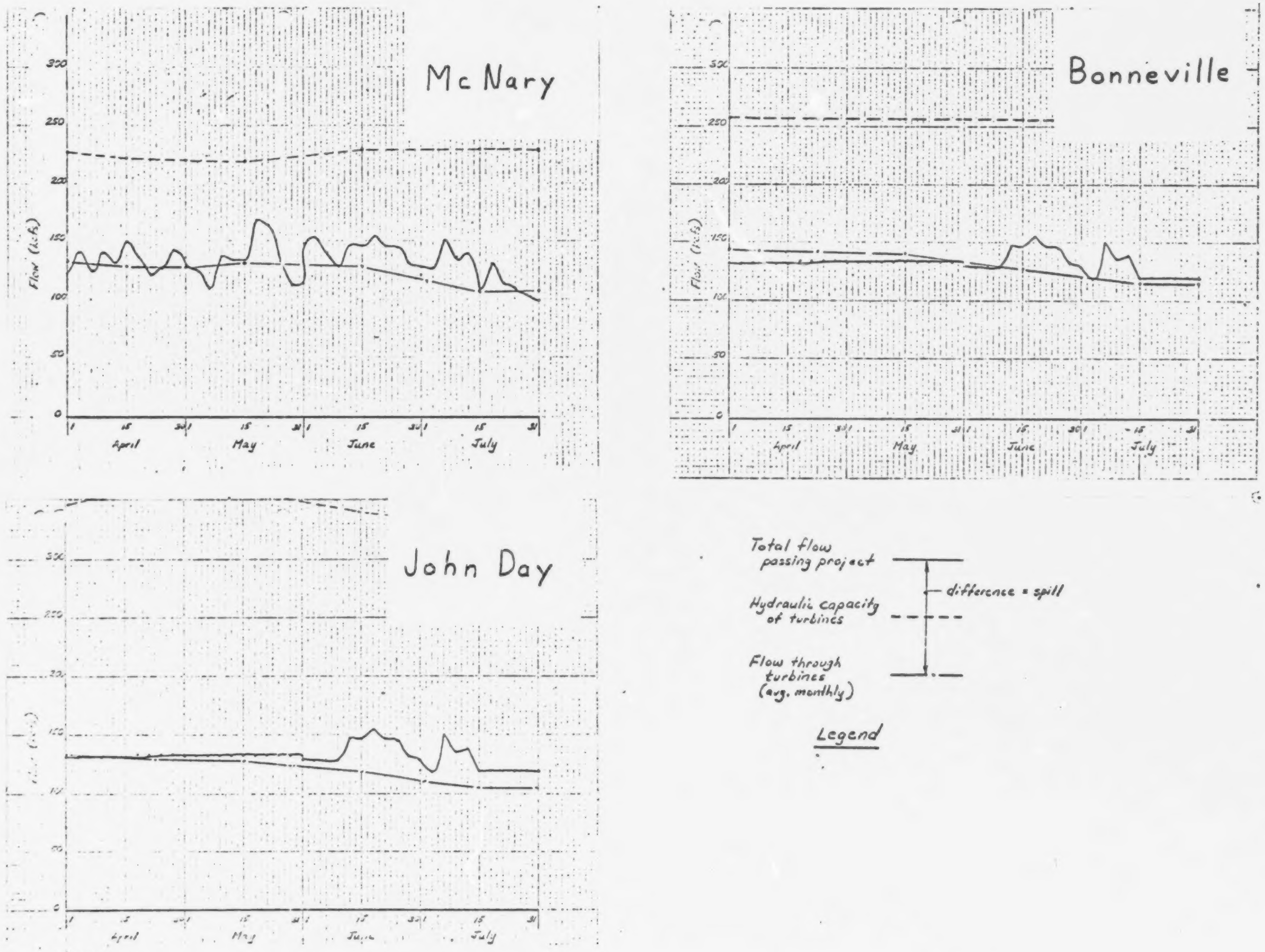

Figure 10b(3) [Continued] Base Condition, 1980, Low Flow Year (1944) localized high negative pressures and leads to the phenomenon known as "cavitation." The high negative pressures cause tiny bubbles of water vapor to form and when they collapse (or "implode") in regions of higher pressure, the force of the implosion creates stresses on turbine blades and other surfaces in the water passages. Operation at low loads has also been shown to cause more damage to fish which are passed through the turbines during their downstream migration. For these reasons it is assumed in the "base condition" for 1970 and 1980 that the flows passing through the turbines at a particular hydro project are limited by the amount of energy load to be served by that project. The total hydraulic capacity of the turbines, of course, defines the maximum amount of flow which could be passed under any conditions. As shown on the graphs in Figure 10, the flows which pass through turbines at a project are normally less than the total hydraulic capacity. This is done to maintain some generating reserves to provide for unscheduled or forced outages, scheduled outages for maintenance and repairs, and contingencies for unanticipated load growth. The amount of reserve varies among projects.

It is the total energy load then, not the total hydraulic capacity, that presently determines how much water can be passed through the turbines. It follows, that addition of generating units at the various hydro projects prior to corresponding growth in regional power demand will not help solve the nitrogen problem. In fact, premature installation of the units may eliminate flexibility in the use of empty turbine bays to bypass flow (discussed later) and thus may actually aggravate the problem. Figure 11 shows that, unfortunately from a nitrogen standpoint, the period of lowest power demand annually coincides with the period of highest stream flows. The curves representing median water and critical low water conditions terminate where they meet the total energy load curve. Any flows above those points could not, on the average, generate power and would pass over spillways. In a later section a method of designing powerhouse facilities to pass flows while generating very small amounts of power is described. If this measure could be implemented, existing generating units plus new ones could contribute significantly to reduction of spills and nitrogen levels.

The flow hydrographs shown on Figure 10 should be viewed as only an example of the flow patterns which could be associated with floods of the three magnitudes considered. The hydrographs of floods in future years could have a completely different shape than the ones presented in this report.

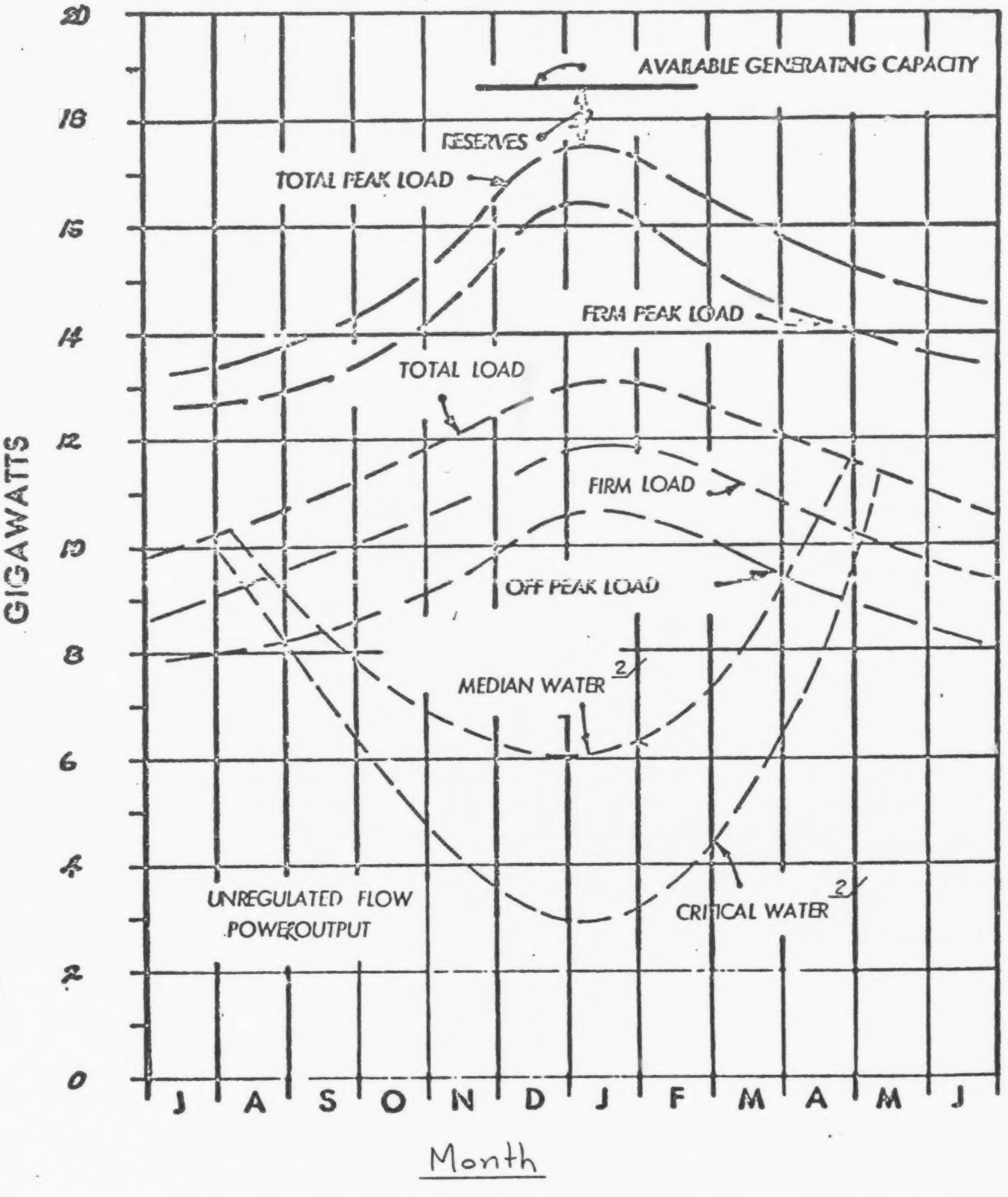

Figure 11 Annual Loads and Resources, Pacific Northwest[1]

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[1] Reference: Anonymous, 1971C

[2] Converted to equivalent power production.

Description of Conditions in 1970

The series of graphs shown on Figure 10a for the 1970 level of development reveal that even in a year of average flows the magnitudes and durations of flows passing over spillways of dams in the Columbia and Snake Rivers would be great enough to produce nitrogen levels considered hazardous to fish. For example, in an average year at McNary Dam (1952), spills of 175,000 cfs could last for about two and a half months. Using Figure 7 as a guide, these spills could produce nitrogen supersaturation levels of about 135 percent. Evidence presented in the "Biological Evidence" section of this report indicates that nitrogen levels above 105 percent produce symptoms of gas bubble disease in fish and that levels above 120 percent are lethal. Spills of 30,000 cfs or more at the lower Snake River Projects -- Little Goose, Lower Monumental, and Ice Harbor -- could last for about two months in an average year (1932). The data in Figure 6 indicates this level of spill would produce nitrogen supersaturation levels of 120 percent or more. In the low flow year (one which would be exceeded 95 percent of the time), spills and nitrogen levels would be low enough to be considered safe for fish migrating up and down the rivers. Although it is not certain at what specific river flow levels nitrogen problems occur, it is apparent that the threshold level is somewhere between low and average flows.

The levels of nitrogen supersaturation produced by given levels of spillway discharge are based on very limited data and in the discussion above and in following paragraphs should be considered as only rough estimates of the magnitude of the problem produced in each case. The actual level of nitrogen supersaturation below a particular dam at a particular time depends on many factors, the most significant being the amount of spilling and nitrogen entrainment in the river system upstream of the given dam as well as the spill at the given dam.

The water moving downstream through the series of pools behind the dams in the Columbia and lower Snake Rivers circulates insufficiently to rid itself of the gas entrained at an upstream spillway. On the contrary, as the water mass moves downstream, picking up more gas at each successive spillway, the level of supersaturation often tends to increase. It is apparent that detailed studies will be required to develop reliable relationships between spill conditions throughout the river system and nitrogen levels at particular projects. Along this line, the Corps of Engineers has had developed under contract a mathematical model for predicting nitrogen levels produced by various spillway-stilling basin configurations under given combinations of spillway and powerhouse operations.

Predicted Conditions in 1980

Figure 10b shows the hydrographs and flows through turbine-generator units expected under normal operating conditions (no nitrogen controls) in the year 1980. This set of graphs shows that, if present planning forecasts and construction schedules materialize, by 1980 there will be significant reductions in spills throughout the Columbia and Snake River systems.

However, nitrogen supersaturation will continue to be a problem.

In the operation studies of the 1980 level of development it was assumed that only three generators would be installed at Little Goose. However, recent installation schedules call for all six units to be installed in that project prior to 1980, and the following comments are based on this revision.

In both high and average flow years, spills at many projects in the main stem Columbia River will be at levels high enough to produce lethal concentrations of dissolved nitrogen. For example, at McNary spills of 175,000 cfs or more would last for two months in the high year and one month in the average year. These spills would produce nitrogen supersaturation levels of about 135 percent, depending on forebay conditions.

On the lower Snake River, under the expected 1980 conditions, Figure 10b shows that total river flows above 100,000 cfs could last for about four and a half months in the high flow year and about one half month in the average year. At the new Lower Granite Project these flows would require spills of over 30,000 cfs. The levels of nitrogen supersaturation which this spill will produce at Lower Granite is unknown at this time. Studies are currently being conducted by the Corps of Engineers to install additional bypass capacity and to devise a spillway configuration for that project which will not entrain excessive amounts of gas. The success of this effort is essential to the solution of nitrogen problems in the lower Snake River because the effects of conditions at Lower Granite will carry downstream to the other Snake projects. For example, at a total river flow of 160,000 cfs, Little Goose Project could pass a maximum of 130,000 cfs through turbines and would have to spill 30,000 cfs. If Lower Granite were not entraining nitrogen, the water arriving at Little Goose might be close to 100 percent of saturation. The 130,000 cfs passing through the turbines at Little Goose would also be at 100 percent saturation, the 30,000 cfs spill would be about 120 percent supersaturated, giving a mixture some distance below Little Goose which would be only 104 percent supersaturated. If, on the other hand, spills at Lower Granite produce a mixture which is 120 percent supersaturated, the mixture below Little Goose would be supersaturated by 120 percent or more. The condition would then worsen down through Lower Monumental and Ice Harbor since little equilibration would occur in the slow moving pools between the projects.

The hydrographs in Figure 10b show that in a high flow year on the lower Snake, total regulated river flows above 200,000 cfs could last for about one month. Rough calculations show that, if the flow below the new Lower Granite Project were not supersaturated with nitrogen and all projects were passing maximum flows through turbines, the resulting spillway discharges could produce nitrogen supersaturation levels as high as 135 percent below the most downstream project (Ice Harbor) during that period. In an average year on the Snake, total flows of 160,000 cfs or more would last less than a week and would produce under conditions described above, a lethal level of nitrogen supersaturation (120 percent or more) in the mixed flow below Ice Harbor. Flows of 130,000 cfs or more would last for about one and a half weeks in an average flow year. Under the above conditions, a flow of 130,000 cfs would require spilling only at Ice Harbor, and nitrogen concentrations in the mixed flows would be below hazardous levels (105 percent of saturation). Directly below the Ice Harbor spillway, however, that river flow would produce a supersaturation level of 110 percent or more. This condition would be less hazardous for the downstream migrants, most of which would tend to flush out of the supersaturated zone before gas bubble disease could occur. Upstream migrating adults, on the other hand, are attracted to the spillway flows and can remain trapped in the zone of supersaturation long enough to contract the disease.

If Lower Granite also increases nitrogen levels, conditions downstream will be correspondingly worse than stated above. Again, in the low flow year, there will probably be no spills and no nitrogen problems in either the Columbia or Snake Rivers.

The foregoing analysis of 1970 and 1980 conditions presents the situation as it exists today and as it would develop if no attention were given to the nitrogen problem. As the system of dams, reservoirs, and power generating facilities expands through the years, the volumes of spill at the various projects will be reduced. However, without additional control measures the reductions in volume of spill, even in an average year, will not be great enough to reduce nitrogen supersaturation to levels which would be considered safe for fish.

Proposed Methods of Controlling Nitrogen, Within Normal Constraints

Operational

As noted before, one broad category of solutions to nitrogen supersaturation problems are designated "operational." These types of solutions are those which can be implemented through adjustment of reservoir filling and release schedules, through transfer of power loads among the various projects, or any other methods which do not require structural modifications to dams or power units. Several solutions of this type were partially implemented by the Corps of Engineers, Bonneville Power Administration, and the state and federal fisheries agencies in an effort to reduce losses to fish during the exceptionally high flows experienced this year. (Based on current forecasts the flood occurring this year would be equalled or exceeded once in seven to ten years.)

The complexity of the flow regulations and power generation network in the Columbia-Snake River system, and the rapid rate at which system components change from year to year make it very difficult to select a particular year or set of system conditions for an analysis of the effectiveness of the various methods of controlling spills and nitrogen. However, since storage in three major new reservoirs -- Libby, Mica, and Dworshak -- is expected to be operational by about 1975 and since no significant additional storage will be constructed between then and 1980, the effectiveness of the various engineering measures will be related to the expected river regulation in the 1975-1980 period.

The first operational type solution studied was a modification in the use of the five million acre-feet of active storage behind Grand Coulee reservoir. Preliminary computer operation studies have been made by the Corps of Engineers to determine the effects of this type of manipulation on downstream river flows. Figure 12 shows the results of this analysis. The hydrograph of the 1933 flood at The Dalles project was used in this analysis. The 1933 flood was slightly larger than the 1952 flood; it, therefore, has a frequency of recurrence of somewhere between one in two years and one in ten years. The horizontal line at 450,000 cfs designates the flow at bank full stage. Flows above this stage would begin to flood downstream areas.

The curve labeled "Current Operating Plan" would result from the regulation of Grand Coulee Dam according to rules established in the proposed Flood Control Operating Plan for Columbia River Storage. The curve marked "Minimum Spill Plan" represents the flows which would result from an operation of Grand Coulee Dam to provide the greatest control of spills for the longest period during the spring freshet season. The criterion for deriving this operation plan is the assumption that a large spill of short duration is less damaging to the total fish resource than prolonged spills at lower levels. Therefore, this operation plan is designed to control river flows to a maximum of 250,000 cfs for as long as possible, then, after the storage throughout the system is exhausted, to let the excess flows go in one short high peak. An approximation of the magnitude of spillway discharges under these two operating plans can be made by comparing the hydrographs in Figure 12 with the hydraulic capacities of the hydroelectric projects shown on Figure 9, and assuming the projects could be operated at their stated capacities. It may also be assumed that the flows at the other downstream projects -- McNary, John Day, and Bonneville -- are roughly the same as shown for The Dalles. At McNary, for example, the "Minimum Spill" plan would result in a spillway discharge in excess of 20,000 cfs for a period of nearly two months, producing (depending on upriver conditions) nitrogen levels above 120 percent of saturation during that period. Under the "Current Operating Plan" the same level of spill and nitrogen supersaturation would last about two weeks longer. At John Day and The Dalles, the hydraulic capacity of the turbines will be increased to about 350,000 cfs by 1975. Both operating plans would therefore result in spilling at those projects for about fifteen days. The "Current Plan" however would allow spills to be held to 10,000 cfs, whereas the "Minimum Spill" plan would allow a peak spillway discharge of 170,000 cfs. At Bonneville, until the six

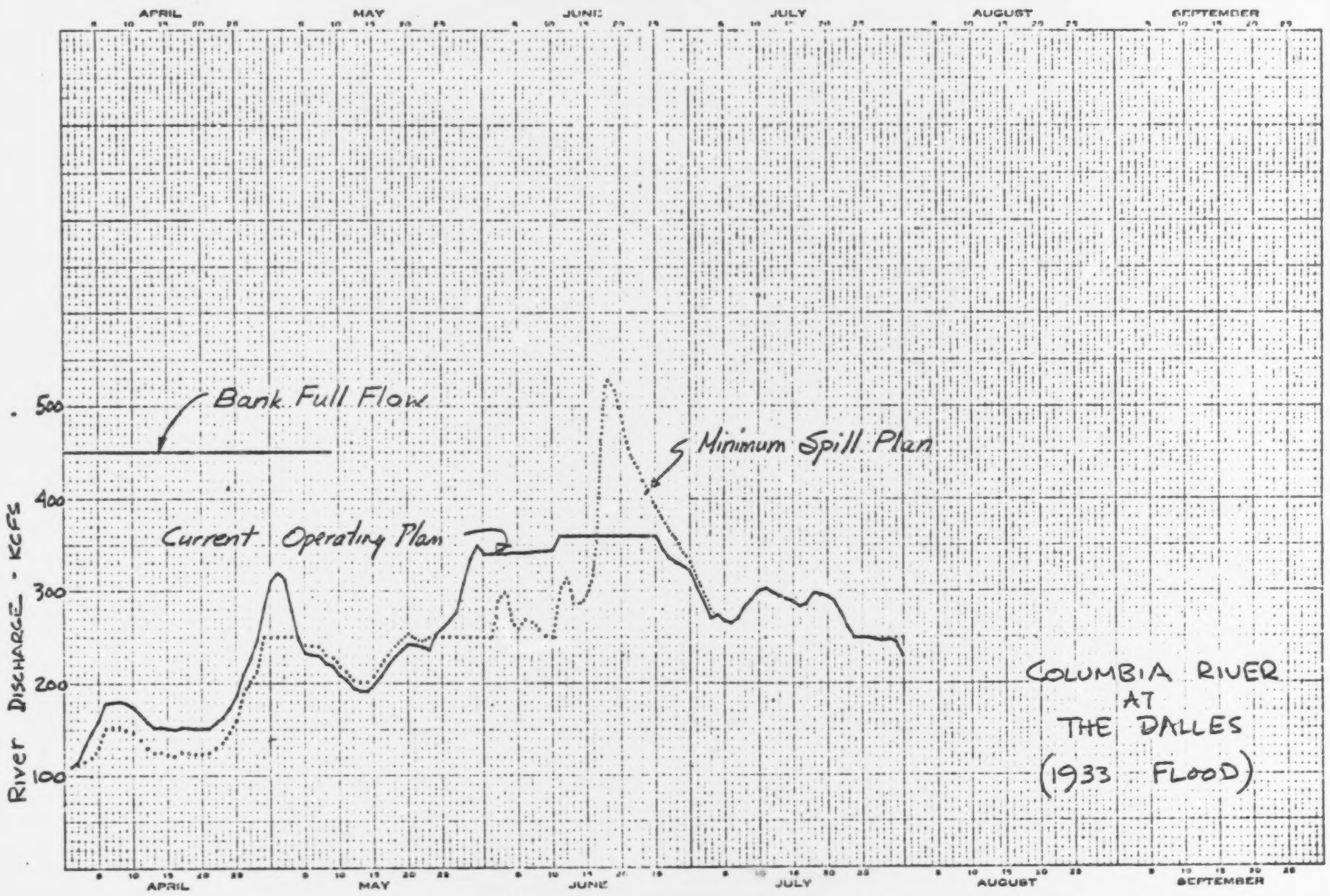

Figure 12 Hydrographs of Flow at The Dalles Resulting from Modified Operation of Grand Coulee Dam (1933 Flood) 1/

1/ Prepared by Corps of Engineers, North Pacific Division.

additional generating units are installed (now scheduled for 1978-1980), spillway discharges in excess of 40,000 cfs would last for three months under either plan. These discharges at Bonneville would produce nitrogen supersaturation levels above 120 percent during those months. After the additional generating units are installed at Bonneville the period of these critical spills would be reduced to one month under the "Current Plan" and to fifteen days under the "Minimum Spill Plan."

The benefit of the "Minimum Spill Plan" is most obvious at Bonneville and McNary Projects, where the period of critical spills can be reduced. This would reduce the chances for migrating fish to be exposed to lethal nitrogen levels and would allow hatchery releases of fingerlings to be better timed to avoid the period of high spills. At Bonneville, however, the benefit will not be realized until the second powerhouse is completed and the additional turbines are operable.

There would be some consequences to the "Minimum Spill" type of operation, however, due to the increased potential for downstream flooding. The operation may cause flood control storage in upstream projects to be completely filled early in the freshet season before the danger of high stream flows has diminished. The capacity to control later peak flows is this exhausted. The potential for serious downstream flooding is accordingly increased. As shown on Figure 12 the "Minimum Spill" operation results in peak flood flows which are some 70,000 cfs above bank full stage (for the hydrograph of the 1933 event).

Thus far all of the computer operation studies used in the analyses have assumed full use of the storage available in Canada through provisions of the Columbia River Treaty between Canada and the United States. In a later section this upstream storage availability will be discussed in more detail.

Another operational measure which could help to reduce spillway flows, and thereby reduce nitrogen levels, is a modified operation of navigation locks at certain projects. The raising and lowering of the water level inside the lock is accomplished by opening and closing sets of valves on the upstream and downstream end of a large conduit located beneath the lock. There is a possibility that during conditions of high flow the valves at both ends of this conduit could be fully opened to allow up to 15,000 cfs to be passed through the locks. Spillway releases would be reduced accordingly. Tests are being planned now to determine whether this operation is structurally safe and whether the flow released in such a manner is actually low in nitrogen content. Problems which could arise with this measure are cavitation in the bypass facilities, surges caused by closing the valves from a fully open position, and possible nitrogen entrainment in the bypassed water through air vents in the valves. A test of this bypass method this year at Little Goose Project produced unacceptable surges and vibrations in the emptying valve shafts. Further tests will be necessary to determine whether this problem can be eliminated and whether the problem is unique at Little Goose, however, prospects at this time appear dim. There may also be conflicts arising during periods when the locks must be operated for navigation. Locking operations on the Snake River during the high flow season occur only a few times per day, whereas on the Lower Columbia they are more frequent -- 10 to 12 times per day. Each operation requires 45 minutes to 1 hour. The effect of bypassing intermittently must therefore be determined.

Navigation locks have been installed in the Lower Columbia projects (McNary, John Day, The Dalles, and Bonneville), and also in the lower Snake projects (Lower Granite, which is under construction; Little Goose; Lower Monumental and Ice Harbor). The possibility of bypassing flows at these projects should therefore be considered. In addition, special studies have been made by the Corps of Engineers on the feasibility of installing navigation locks at some of the upstream Columbia projects (Rocky Reach, Rock Island, Wanapum, and Priest Rapids). Although a bypass capability of 15,000 cfs is not particularly large compared to flood flows in an average year; when combined with other solutions for reducing flows over spillways it could be a significant partial remedy.

Other modifications to the reservoir regulation procedures are available for control of excessive spills and some were implemented during the excessively high runoff period this year. These other methods involve modification of spilling schedules during periods of fish passage, varying the pattern of release through various spillway bays, and establishment of priorities for spilling at the various projects. These types of modifications to reservoir regulation can be very effective, especially with close coordination between the operating agencies and the fisheries agencies. However, since these modifications to system regulation take place in response to critical situations as they arise, it is difficult to predict their effects in future years. Although it is difficult to quantify the results of this type of coordinated reservoir regulation, it is apparent now that this coordination will be an essential element in the success of an integrated solution of the nitrogen supersaturation problem. This year, for example, fishery agencies cooperated to schedule the release of nearly all hatchery-reared fingerling fish in the Columbia River (40 million out of a total of about 60 million) within a two-day period. Reservoirs and power-generating facilities were operated to produce the least possible amount of spill on those days and for about five days thereafter, to allow the young fish to move downstream in water which had the lowest amount of nitrogen possible during this unusually high flow period. The reduction in spills was accomplished by storing about 1 1/4 million acre-feet of water in eight reservoirs throughout the system, and by transferring power loads to allow the lower Columbia and Snake hydroelectric projects to generate at or near their full capacity.

Another set of operational modifications for nitrogen control falls into the broad category of power load transfer. Since spillway flows at certain dams tend to produce more nitrogen than at others, and because some projects are located in river reaches where large numbers of migrating fish are present, it is desirable to reduce the spills at these projects as much as possible and to accordingly allow more spills to pass over less critical projects.

A vast network of power transmission circuits links generating plants in the Pacific Northwest to load centers. Interconnections between generating systems -- public, private, and federal -- provide a high degree of flexibility in distributing power among the load centers. This flexibility makes it possible, during periods of high river flows, to transfer more of the generating load to the hydroelectric plants located at critical dams. This has the effect of causing the turbines at these critical projects to pass flows at or near their hydraulic capacity, with correspondingly less flows over the spillways. At the less critical projects the power generation must be reduced and the spillway flows increased. To make maximum use of the system flexibility the public, private (Idaho Power Company), and federal power operating agencies and the Federal Power Commission should be included in any coordinated effort to solve the nitrogen problem.

This type of load transfer was another key feature of the coordination which was accomplished this year in an effort to reduce the overall impact of nitrogen supersaturation. The goal of this operation was to generate as much power as possible at the downstream projects in both the Columbia and the Snake Rivers. The reason for this was that even though spills at upstream projects also produce nitrogen, the fish runs from all the tributaries converge downstream. Therefore, reducing the hazard downstream has a potential for protecting the greatest number of fish. It must be noted here that the hydraulic capacity of the turbine-generator units at the various projects becomes a limiting factor in this load transfer operation. Also, since many of the dams involved in the transfer relationships are in public and private ownership, a high degree of cooperation among the various generating agencies is required.

Arrangements may also be made to transfer power during these critical high flow periods to agencies outside the Columbia-North Pacific Region. The Northwest Power Pool is interconnected with the Rocky Mountain Power Pool, the Pacific Southwest, and the New Mexico area. Transfers of this nature were accomplished this year. One arrangement included transfer of energy to British Columbia Hydro and Power Authority. Power generated in the Pacific Northwest Region at critical projects was delivered to the Canadian utility. This allowed BC Hydro to store water in their new Wiliston Lake Project in the Peace River system in lieu of releasing it for power generation during the period of high stream flow. This arrangement was only possible this year because Williston Lake is in the process of filling. In later years, it is anticipated that this alternative will not be available for reduction of spills at the Lower Columbia projects. Another arrangement which was accomplished this year was the delivery of power produced at critical projects to West Kootenay Power and Light (The British Columbia utility whose plants are on the Kootenay River below Nelson, B. C.), in exchange for immediate spill on their system. Unlike the Peace River arrangement, this transfer had no effect on reducing the amount of flow passing downstream, but it did allow more generation of power at the critical projects. Transfers to West Kootenay Power and Light could be made in future years.

Any load transfer of this nature would be limited by two factors: (1) The existing and future transmission intertie line capacity; and, (2) The actual availability of power load in the regions to which the load is to be transferred. The effective capacity of the intertie lines to the Pacific-Southwest Region is normally about 1900 megawatts (two a-c lines with capacities of 600 megawatts (MW) each plus one d-c line with a capacity of 700 megawatts). The recent earthquake in Southern California rendered the d-c line temporily inoperable; consequently, the two a-c lines were each increased to 800 MW, for a total present capacity of 1600 MW. This situation is expected to continue for about a year and a half while the d-c intertie facility is under repair. Future plans include an additional 700 MW d-c line. This could produce a total future capacity of about 2600 MW. The intertie to West Kootnay Power and Light has a capability of carrying about 200 MW and the intertie to B.C. Hydro can carry about 300 MW. The overall effect of these types of transfers, of course, is to increase the amount of water which can be passed through turbine units at critical projects in this region. However, the fact that the success of the transfer depends upon the need for the power in the other regions makes it very difficult at this time to predict the magnitude of the reduction of spills in the future that could be realized from this type of transfer. Bonneville Power Administration has indicated that although this information on predicted conditions is not available now, computer programs and the basic data required to determine the effects in future years are available and could be used to analyze alternative methods of power transfers and power generation for an optimum operation for control of nitrogen. These studies should begin as soon as possible.

The computer studies on which the turbine flows in Figure 10 were based, did account for transfers of power within the United States. This means that, due to present intertie capacity, the maximum additional load which could be transferred is about 500 MW to British Columbia. At many hydroelectric projects in the Columbua system about 7 MW can be generated by each 1000 cfs passing through the turbines. Transferring 500 MW of additional load to Canada could therefore reduce spills by 71,000 cfs. This reduction could be taken at a single project or split between several, depending on turbine capacity and spilling priority.

Structural

An approach to finding structural solutions to the nitrogen supersaturation problem depends on some basic assumptions concerning the relationship between the project design and the levels of nitrogen supersaturation. These assumptions are stated in the first paragraph of the Methodology section of this chapter. Figure 13 shows the basic layout of a typical hydroelectric project.

One very promising structural measure is being tested for its effectiveness this year. This involves the use of slotted gates in empty "skeleton" bays of existing powerhouse units. Many dams in the Columbia and Snake Rivers have a number of empty turbine-generator bays in their powerhouses to provide space for additional generators that will be needed in future years. The actual installation of the generating units in the empty bays is accomplished on an as-needed basis and in response to expected power demands in the near future. A sectional view of a typical skeleton bay is shown in Figure 14. The intake structure and the tailrace structure are complete, but the concrete has been omitted in the area where the future turbine will be installed. Figure 15 shows a similar structure with the turbine and generator in place.

These skeleton bays are structurally designed to operate only if the turbine-generator combination is in place and operating to control flow and absorb energy. Consequently, until the generating units are installed and operable, the bays are sealed from any flow by placing concrete stoplogs in the intake structure and draft tubes.

The Corps of Engineers conducted model tests to determine whether flows could be passed through these empty bays and thus help reduce flows over the spillway. The tests indicated that unacceptable flow conditions and structural stress would result from this operation unless a temporary means of controlling flow and dissipating energy were provided. Further tests showed that a multi-orified (slotted) gate, positioned in the bulkhead slot in the intake structure, would provide the necessary control. With the slotted gates in place, the skeleton bays in projects on the lower Snake River should have roughly the same hydraulic capacity as they would have with turbine-generator units operating (about 22,000 cfs per bay).

This year, the Corps of Engineers awarded contracts for the construction and installation of full size slotted gates in one of the three empty bays at Little Goose Dam on the lower Snake River (see Figure 16). Three gates are required per bay. Results of this prototype test showed that the gates functioned to pass water with no apparent structural damage to the bulkhead

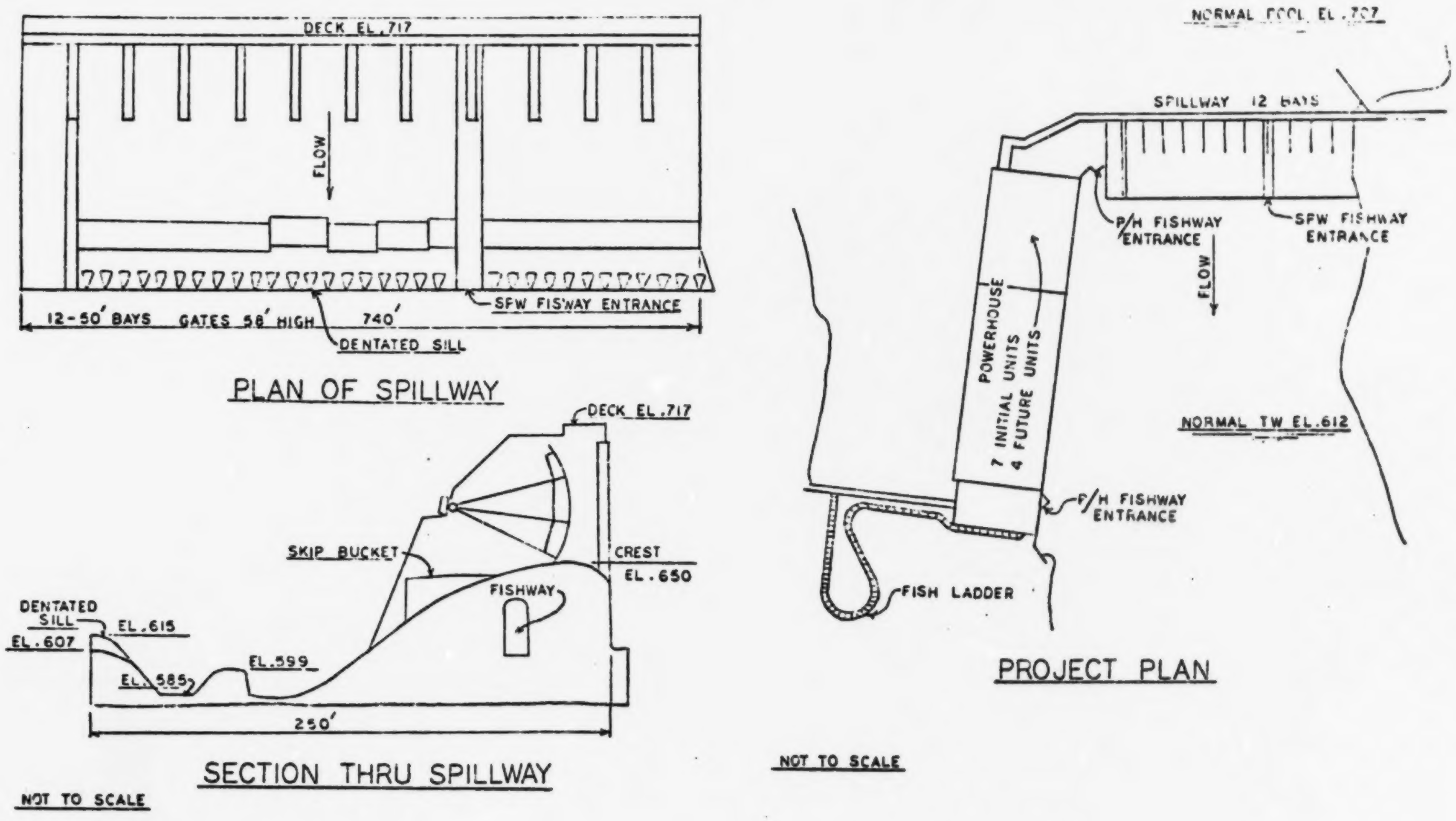
DECK EL.717
FLOW
12-50' BAYS
GATES 58' HIGH
740'
DENTATED SILL
SFW FISWAY ENTRANCE
PLAN OF SPILLWAY
DECK EL.717
SKIP BUCKET
CREST
EL.650
FISHWAY
DENTATED SILL
EL.607
EL.615
EL.585
EL.599
250'
SECTION THRU SPILLWAY
NOT TO SCALE
NORMAL POOL EL.707
SPILLWAY 12 BAYS
P/H FISHWAY ENTRANCE
SFW FISHWAY ENTRANCE
FLOW
POWERHOUSE
7 INITIAL UNITS
4 FUTURE UNITS
NORMAL TW EL.612
P/H FISHWAY ENTRANCE
FISH LADDER
PROJECT PLAN
NOT TO SCALE

Figure 13 Basic Layout of Structures in a Typical Hydroelectric Project (Rocky Reach)1/

1/ Prepared by Corps of Engineers, North Pacific Division.

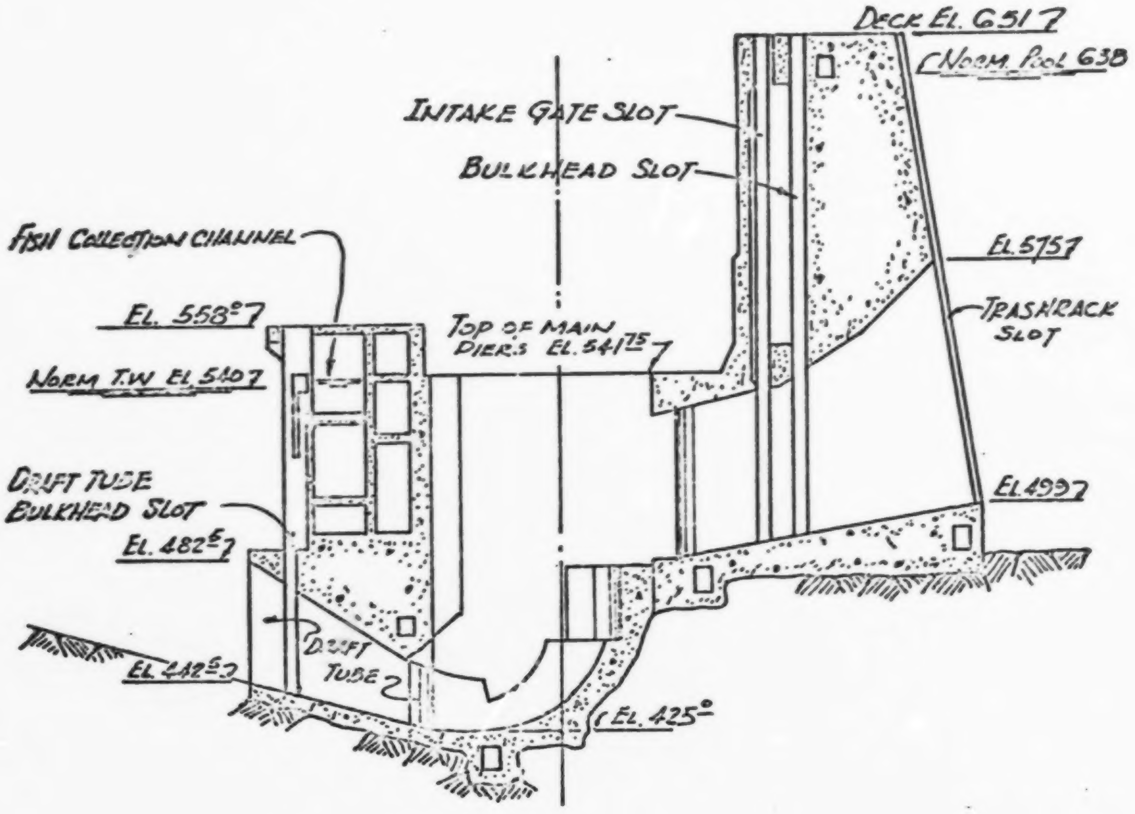
DECK EL. 651
NORM. POOL 638
INTAKE GATE SLOT
BULKHEAD SLOT
FISH COLLECTION CHANNEL
EL. 575
EL. 558^{0}
TOP OF MAIN PIERS EL. 541^{75}
TRASHRACK SLOT
NORM. T.W. EL. 540
DRIFT TUBE BULKHEAD SLOT
EL. 499
EL. 482^{5}
DRIFT TUBE
EL. 442^{5}
EL. 425^{0}

Figure 14 Section Through Skeleton Bay--Little Goose Project

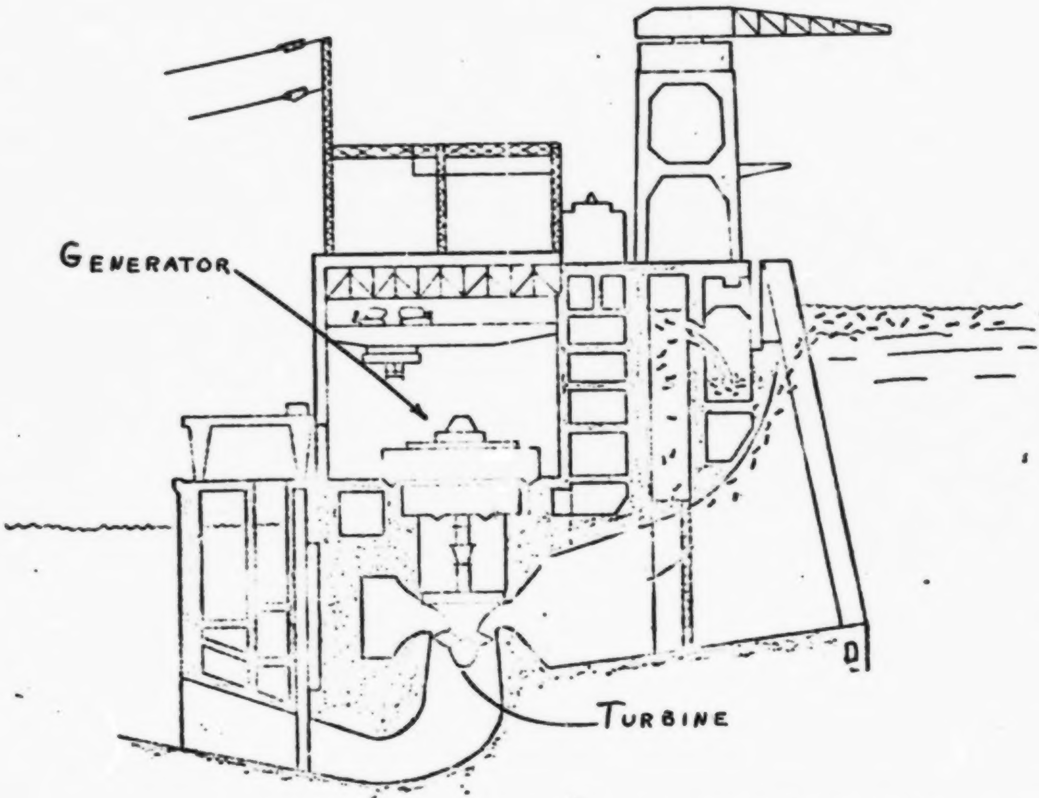
GENERATOR
TURBINE

Figure 15 Section Through a Typical Turbine--Generator Bay

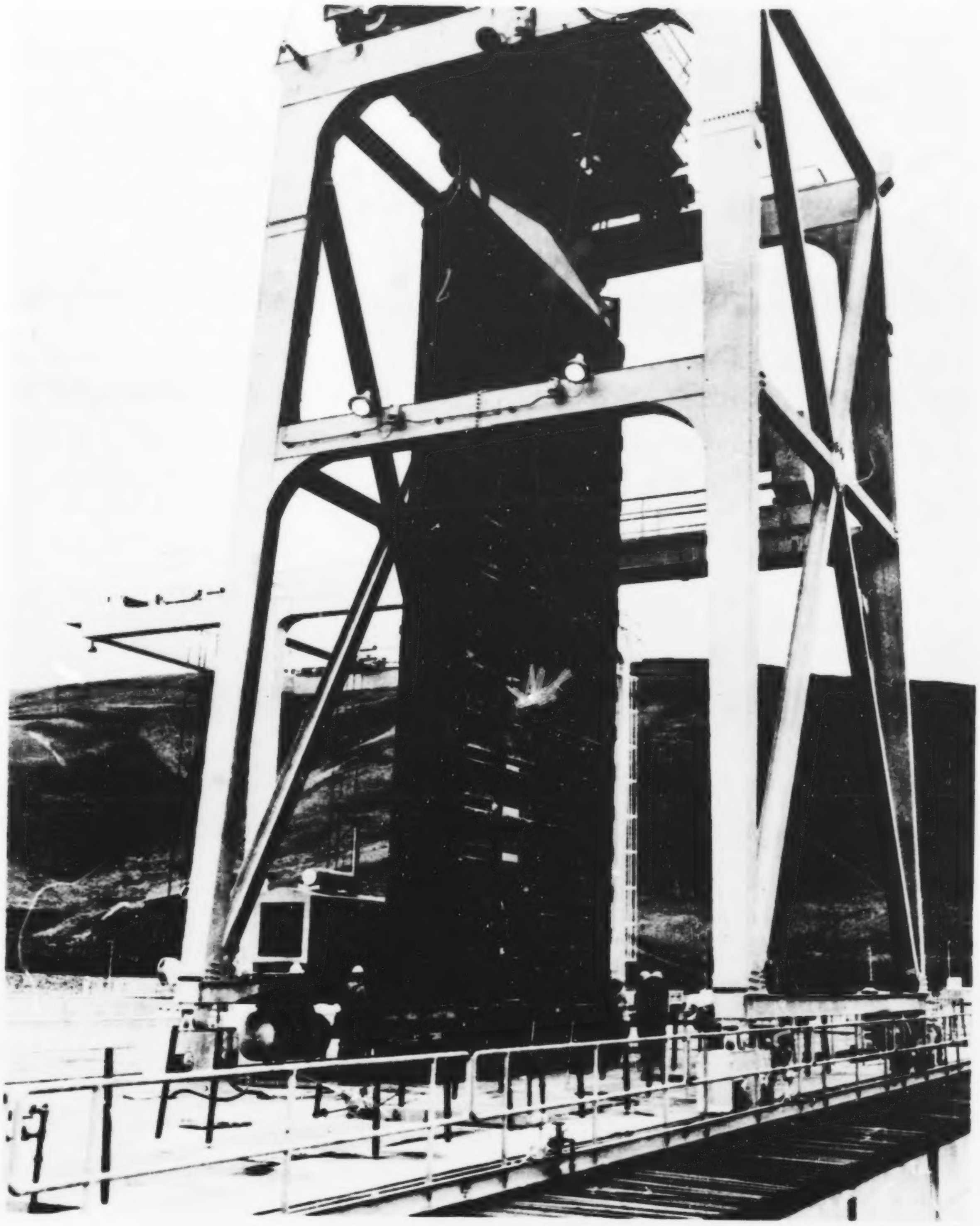

Figure 16 - Prototype Slotted Gate Being Installed at Little Goose Project

or to the skeleton bay. Water samples collected during the test by the National Marine Fisheries Service (Department of Commerce) in the forebay, skeleton bay, and downstream showed that water passing through the dam in this manner did not increase in nitrogen content.

Two other existing dams on the lower Snake River -- Lower Monumental and Little Goose -- each presently has three generating units installed with a total hydraulic capacity of about 66,000 cfs; Ice Harbor has a hydraulic capacity through its three turbines of about 45,000 cfs. In addition, each of these projects now has three empty skeleton bays which could, with the modifications described above, be used to bypass additional water. If all three of these additional bays were fitted with slotted gates and allowed to pass water, the flow capacity through each project would be increased to about 130,000 cfs. Ice Harbor, with a lower initial capacity would only be able to pass about 105,000 cfs under this arrangement. The advantage of this scheme, of course, is that each project would be capable of passing through non-nitrogen entraining facilities quantities of flow roughly equal to their full hydraulic capacity, without having to wait until the additional generating units are actually installed and needed to serve power demands.

Using the hydrographs in Figure 10, the effects of passing these additional flows through the powerhouse can readily be predicted. Assuming the lower Snake projects are loaded to capacity, the magnitude and duration of spilling would be greatly reduced with correspondingly less entrainment of gas. However, preliminary analyses indicate that nitrogen levels will still be high enough during the periods of peak flows to be hazardous to fish in years with average flows and higher. After 1975 a regulated river flow of 160,000 cfs or more would last for about one and one half months in the high flow year, and for less than a week in the average flow year. Assuming the total bypass capability were as stated in the preceeding paragraph, a flow of 160,000 cfs would result in spills of 30,000 cfs at Lower Granite, Little Goose and Lower Monumental projects and 55,000 cfs at Ice Harbor. If Lower Granite could be relied upon to add no nitrogen to the system and the flow arriving at Little Goose had zero supersaturation, the nitrogen level below Little Goose in the average year would be 104 percent of saturation, but would increase to 120 percent below Ice Harbor. In the average year regulated flows of 130,000 cfs or more would last about one and a half weeks. A flow of 130,000 cfs would require spilling only at Ice Harbor, with less than hazardous nitrogen levels in the mixed flow below the project. However, as stated in the discussion of the 1980 base condition, the supersaturated flow directly below the spillway would still constitute a hazard for upstream migrating adult salmonids. In a high flow year, river flows of 200,000 cfs or more could last for about one month. The resulting nitrogen level below Little Goose would be 113 percent of saturation and would increase to 135 percent below Ice Harbor. As stated previously, at supersaturation levels above 105 percent fish begin to show symptoms of gas bubble disease and at levels of 120 percent or more significant mortality occurs. Although the hydrographs presented in Figure 10 are unique for a particular historical year, it is reasonable to assume that the period of peak flows and high nitrogen levels described above will occur in any future year at a time when a large portion of the anadromous fish population is migrating up and down the river.

Although the "slotted gate" does not solve the nitrogen problem it does reduce it, and thus increases the probability that in combination with other measures, nitrogen levels may be held to acceptable levels. The desirability of this type of a construction approach cannot be overstated. It offers a multi-purpose partial solution to the problem, allowing the maximum in flexibility in use of the empty bays while waiting for the generating units to be installed and the power generation needed to meet system demand.

Cost estimates for installation of the slotted gates in the lower Snake River projects are presented in Table 2.

TABLE 2

Estimated Costs for Installation of Slotted Gates in Lower Snake River Projects [1/]

	Little Goose	Lower Monumental	Ice Harbor
Total estimated costs	$4,360,000	$4,415,000	$3,400,000
Allocations to date	900,000	0	0
Balance to complete	3,460,000	4,415,000	3,400,000

[1/] Corps of Engineers, North Pacific Division

Approximately $1,500,000 of the cost estimate for each project can be classified as costs for reducing nitrogen saturation. The remaining costs are advance costs related to ultimate development, involving completion of the powerhouse and installation of the last three generating units. On this basis, the total cost, attributable to nitrogen reduction, for modifying the three existing projects on the lower Snake amounts to roughly $4.5 million. This does not include additional costs required at the Lower Granite project, now under construction.

Variations on this scheme have also been proposed, and some of these variations will be incorporated in the program to install bypass capabilities at the lower Snake River projects. One of these variations is called "capped-unit" diversion. With this variation, all the concrete and imbedded items will be placed in the skeleton bay, including the stay vanes, wicket gates, and sealed head cover. In this way, the water passageways can be completed and allowed to begin passing flow, while at the same time allowing the generator construction and installation to proceed as scheduled. Still, under this system, a slotted bulkhead will be required to dissipate the energy in flows passing through the skeleton bay below. This is a desirable variation at dams at which the skeleton bays have been partially completed. In dams which are now under construction another variation is also possible. This is what could be referred to as "slanted" construction. With this version, the skeleton bay would actually be designed and constructed to have sufficient strength and hydraulic characteristics to pass diversion flows through the dam without the need for energy dissipation in another source such as a generator unit or a slotted bulkhead. "Capped-unit" diversion could also be incorporated in this version of the bypass scheme. The "capped-unit" portion of the construction scheme is considered very important because it can provide for continuous diversion capability during the freshet season at the same time that additional generating units are being installed.

The potential for this type of diversion capability at other projects on the Columbia-Snake river system must be examined. In the lower Snake system, if funding is received, full diversion capability will be provided before the 1972 freshet season. At Lower Granite Dam, which is now under construction, present plans call for three turbine-generator units to be operated when the pool is filled in 1975, with three skeleton bays which can be used for diversion at that time. On the Columbia River at Bonneville Dam, generating units are now installed and operating. There is no possibility of the skeleton bay type of diversion until an additional powerhouse is constructed. The second powerhouse at Bonneville is not due for completion until the years 1978-79, so it is possible that the capability for diversion may not be available until those years. (See installation schedule, Table 5, p. 92). At The Dalles, installation of eight more generating units is underway and scheduled for completion by May, 1974. It appears at this time, because of construction scheduling techniques, there is no chance of bypassing water through the eight additional bays. A discussion of these construction scheduling methods is presented later. At John Day, four skeleton bays are available. These skeleton bays are structurally dissimilar from the skeleton bays in the Lower Snake projects and may require additional design modifications before they could be used as flow diversion facilities. However, diversion through these four bays should be considered a definite possibility. McNary Dam has fourteen powerhouse units operable now with no skeleton bays available for diversion. Priest Rapids now has ten powerhouse units operating, there are no empty skeleton bays available now, and it appears from diagrams of the dam that additional powerhouse units or bypass facilities would require major construction. Wanapum Project has presently installed ten powerhouse units with space for six additional units. The amount of construction necessary for bypass capability in these six additional spaces is unknown at this time. Rock Island Project has the lowest hydraulic capacity (about 70,000 cfs) of any of the Columbia River projects at this time, with ten powerhouse units installed. There are tentative plans to provide an additional six units at this project, but judging from sketches of the layout of the dam it would entail a major construction effort. Bypass capability is then considered doubtful at this project also. Rocky Reach has seven powerhouse units installed with four future units. However, these units are due for completion in 1971. It is therefore considered unnecessary to provide skeleton bay type of diversion at the project. Wells Project has ten powerhouse units located directly under the spillway bays, in the spillway section of the dam. There are no plans for construction of future generating units in this project and it appears that major construction would be necessary to provide any form of bypass capability here. Chief Joseph now has 16 generating units installed with 11 more units planned in 1976-78. Chief Joseph Dam utilizes a penstock intake to the turbine generator units, so the diversion through empty bays would be considerably different than the skeleton bays previously described.

However, it does appear that bypass through these empty units is a definite possibility. At Grand Coulee, there are plans for three additional generating units plus a third powerhouse with nine additional units. No information is available about bypass capability.

Figure 17 shows the present potential capacity to pass flow through structures other than the spillway at all the projects, assuming the turbine-generator units were fully loaded. At each of the projects the capacity of the diversion through the skeleton bays was assumed to be roughly equivalent to the hydraulic capacity of the turbine generator units if they were spinning under full load. Also shown, for comparison, are approximate regulated river flows in an average and high water year after Libby, Mica, and Dworshak reservoirs are operational. The low water year (1944) would produce no spills. The flows shown do not account for any effects of some additional manipulation of storage to provide additional control of spills.

It is apparent from Figure 17 that even with the maximum amount of present bypass capability installed there would still be significant spills at many dams. The hydraulic imbalance of the total system, as shown on the figure, is one of the primary causes. There is relatively little useable storage available in most of the "run-of-the-river" projects in the Columbia and Snake Rivers. Consequently, flows past one dam are roughly equal to the releases at the upstream project plus any tributary inflow between the two. So, if a project with a total hydraulic capacity of 450,000 cfs (such as John Day) were passing that flow through its turbines, Bonneville, downstream with a turbine capacity of only 250,000 cfs, would be forced to spill 200,000 cfs or more. This points to the need for some form of additional bypass facilities at many of the projects. This extra bypass facility could take one of several different forms, depending on the needs at the particular projects, but would be required to pass flows in excess of turbine capacities without entraining atmospheric gasses in the water. A few of the ideas which have been proposed to date will be briefly described.

One such facility would be some form of a low level regulating outlet. This type of outlet would be a hole through the dam at a low level, as simple as possible, and with a gated structure to allow flow through the outlet to be regulated

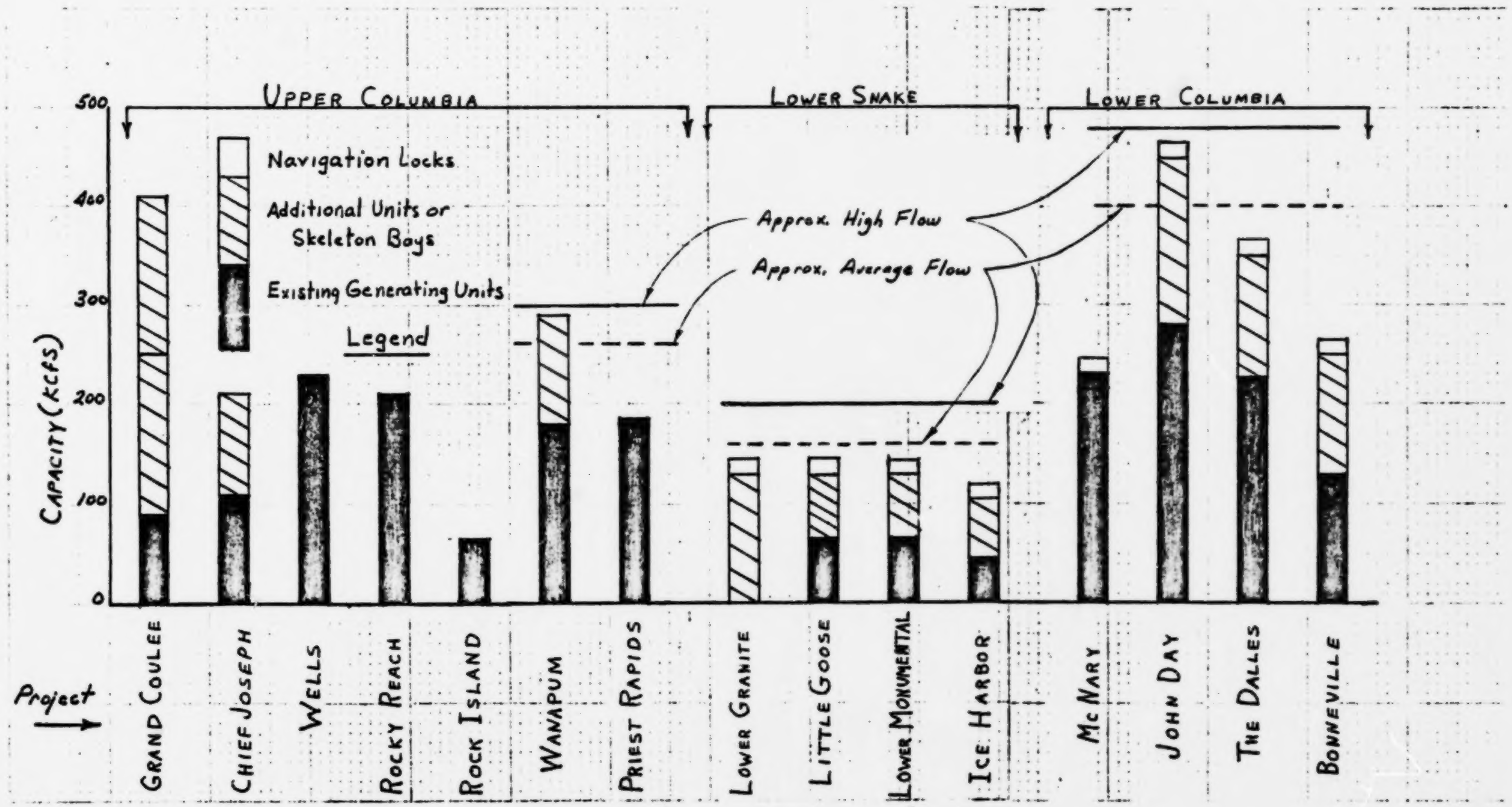

Figure 17 Total Potential Diversion Capacity--Columbia and Snake River Projects

according to the need for passing flood flows (see Figure 18). The outlets could be designed to pass all flows in excess of turbine capacity in a high flow year, say the one in ten year flood. If the downstream outlet discharges far enough below the water level in the stilling basin, the turbulent, energy dissipating hydraulic jump will be completely submerged and will not entrain atmospheric gasses. If sufficient depth is not available for complete submergence, another means of dissipating the energy in the bypassed flow may be required. One such method could be the installation of a multi-orificed gate in the outlet conduit. Energy would then be dissipated before the flow arrived at the outlet, and turbulence and air entrainment in the stilling basin would be minimized.

Another form of bypass facility would be a long, stepped, open channel around the dam. A third method of bypassing flows is closely related to the skeleton bay diversion and would involve special turbine design to allow them to be adjusted to operate "inefficiently." Then, during periods of high flows and low power demand the units could be adjusted to pass flows up to their maximum hydraulic capacity but with reduced power production. Another method of accomplishing this would be to install slotted gates in operational turbine bays. The gates would dissipate much of the energy in the flow so that correspondingly less power would be transferred to the generator. Studies along this line are in progress at the Corps of Engineers District offices and the North Pacific Division Headquarters, but considerably more work needs to be done before feasible designs will be ready.

In reviewing generator installation schedules and turbine-generator construction methods, one additional operational-structural measure for reduction of nitrogen problems should be considered. Normally, when several generator units are to be installed at a project, because of construction and supply scheduling demands, they are built up in a "stair-step" sequence. This means that at any given time different phases of construction are underway at each unit and each is very likely at a different stage of completion. With this method, all the turbine bays need to be dewatered at the same time and are unavailable for diversion of flows until the entire set of new units is nearly complete. A couple of possible solutions to this problem appear to be available. One might be the complete installation of one unit at a time, leaving the other skeleton bays open and available for diversion of flow. Another possible solution would be the "capped-unit" type of construction mentioned earlier. With

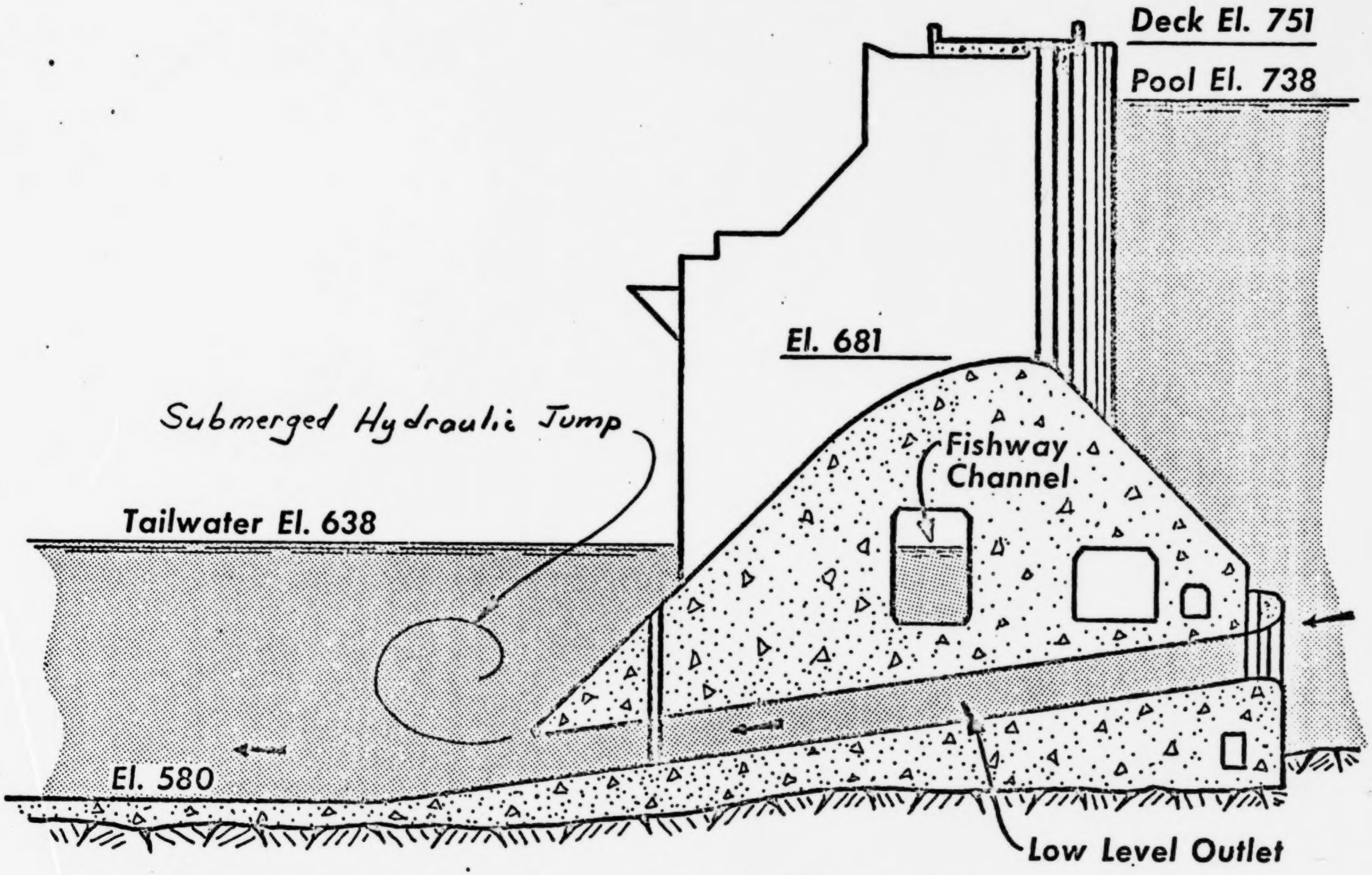
Deck El. 751
Pool El. 738
El. 681
Submerged Hydraulic Jump
Fishway Channel
Tailwater El. 638
El. 580
Low Level Outlet

Figure 18 Proposed Configuration of a Low-Level Regulating Outlet (Lower Granite Spillway) 1/

1/ Corps of Engineers, North Pacific Division that type of construction, all of the units could be worked on simultaneously, while at the same time flows could be bypassed through the lower cavity.

Another type of structural solution which has been given some consideration is a modification of the spillway and stilling basin combination. (Anonymous, 1971C). The basic function of the stilling basin is to provide a structure having the necessary length and depth for energy dissipation (in the form of a hydraulic jump) for all required flows, including the major flood flows. Some available evidence indicates that certain stilling basins tend to produce a lesser supersaturation level than others do. In order to more closely simulate the characteristics of those stilling basins having the lesser and desirable levels of nitrogen saturation, high releases could be concentrated through one or more of the spillway bays. However, since this drastic alteration in spill patterns could seriously jeopardize upstream migrant fish collection and passage, this solution is questionable. To lessen the depth by raising the stilling basin floor could jeopardize the integrity of the structure by providing inadequate depth to dissipate energy for major flood flows.

Recent studies by the Corps of Engineers indicate that it may be possible to modify the spillway structure to cause spillway flows to plunge to a lesser depth in the stilling basin. The concept involves a lip on the downstream face of the spillway structure, which directs small to moderate concentrations of flow along the surface of the tailwater (see Figure 19). Additional studies plus prototype tests will be required before this scheme can be considered feasible. However, it does offer an attractive possibility for safe bypass of some excess flow at many existing projects where provision of other types of bypass structures will be extremely difficult.

Other Methods of Controlling Nitrogen

Additional Reservoir Storage

In this section of the report, the physical possibility of eliminating flood flows over spillways will be discussed, regardless of any present legal or operational restrictions.

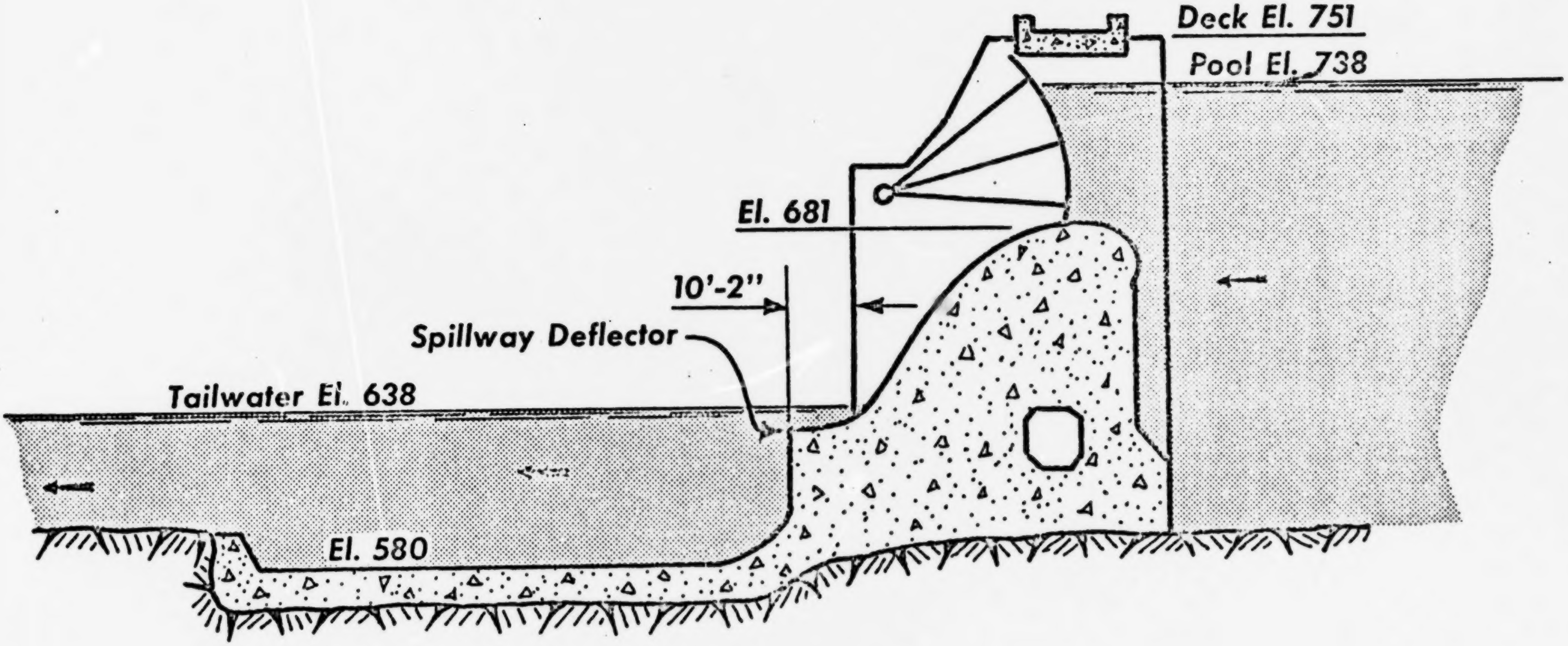
Deck El. 751
Pool El. 738
El. 681
10'-2"
Spillway Deflector
Tailwater El. 638
El. 580

Figure 19 Proposed Configuration of Spillway Deflector (Lower Granite Spillway) 1/

1/ Corps of Engineers, North Pacific Division

One method of reducing spills, of course, would be the establishment of more complete control of flood run-off in the Columbia and Snake River system. The flow of the lower Columbia River is now regulated by upstream storage reservoirs located principally in headwaters areas of the Snake River and in Canada. At present, there is about 22,000,000 acre-feet of active storage. This will soon be increased to nearly 41,000,000 acre-feet when Libby, Mica, and Dworshak Reservoirs, now under construction, are completed (about 1973). Some preliminary computations were made by personnel of the Corps of Engineers to determine the possible effect that some additional storage could have on reducing spills in the lower river. For this analysis it must be noted that a reservoir at any particular point can influence downstream flows only to the extent that the tributary on which the reservoir is located actually contributes flows to the downstream system. Figure 20 shows the effects on the 1980 condition of additional storage at a few projects. For these calculations, approximately 3 million acre-feet of storage was assumed to be constructed on the upper Columbia with about 2.4 million being actually available for flood control, and 5.5 million additional acre-feet of storage would be constructed on the Snake River with approximately 3.8 million being available for flood control. None of this storage is presently authorized and so should be considered highly speculative at this time. However, the analysis does serve to illustrate the effect on stream flows of upstream storage of these rough magnitudes.

Columbia River Treaty Storage

Under terms of the Columbia River Treaty between Canada and the United States (Anonymous, date unknown), 8.45 million acre-feet of Canadian storage is routinely available to the United States for use in their flood control operating plans. Each year by May 1, three Canadian Reservoirs -- Arrow, Duncan and Mica -- are to be drawn down sufficiently to provide this 8.45 million acre-feet of available storage if required for flood control in the U. S. The treaty also requires that Canada operate any additional storage in the Columbia Basin on an "on-call" basis when required by the United States for the purpose of controlling exceptionally high floods. This "on-call" storage could make up to 20,500,000 acre-feet (including the 8,450,000 acre-feet routinely available) of Canadian storage available for flood control in the U. S. For use of the "on-call" storage by the United States, the

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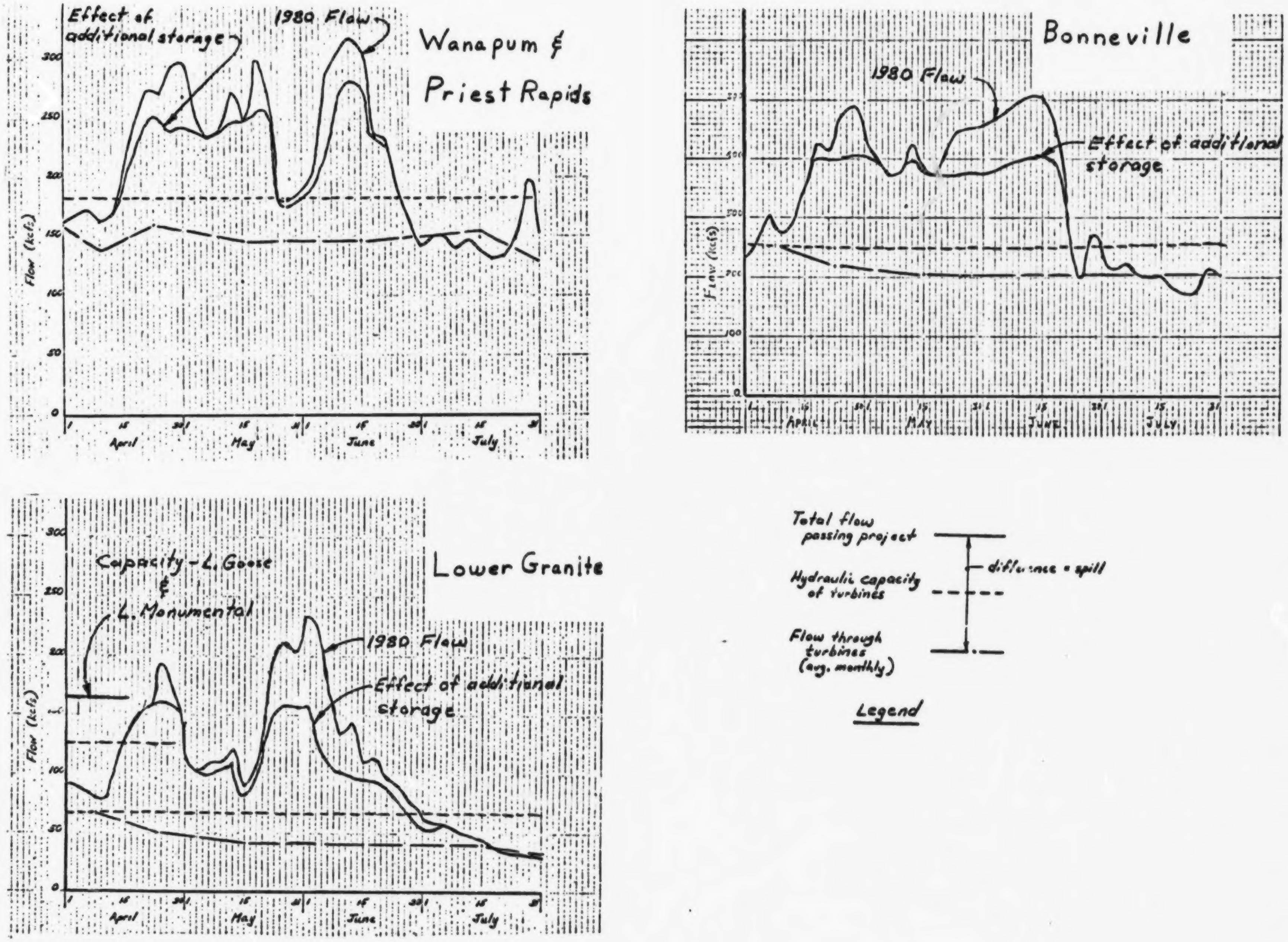

Figure 20a Effect of additional upstream storage, high flow year (1956)

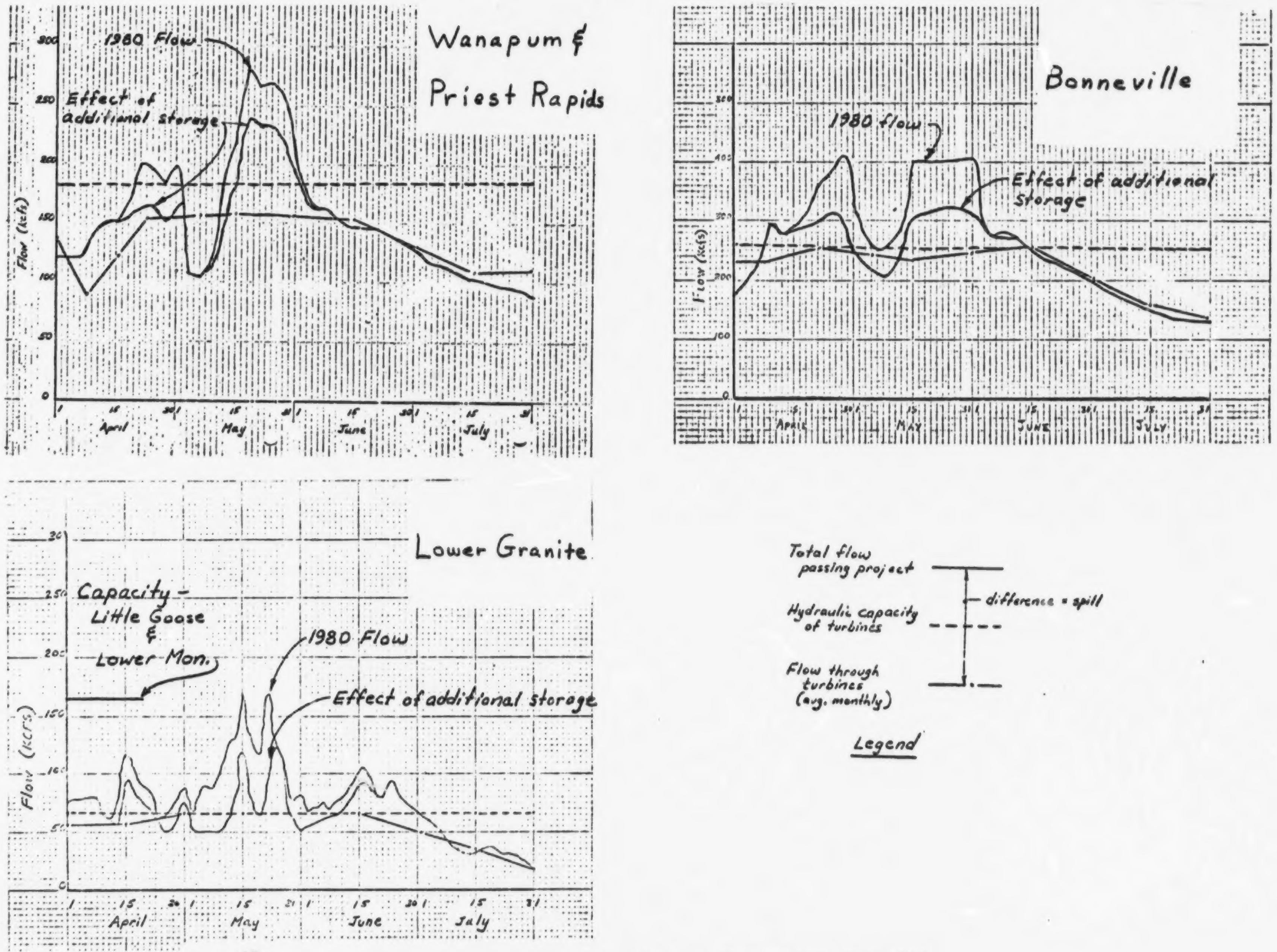

Figure 20b Effect of additional upstream storage, average flow year (Columbia-1952, Snake-1932)

NOT REPRODUCIBLE

U. S. must pay Canada a sum of $1,875,000 each of the first four times the additional storage is called upon. The U. S. must also deliver to Canada electric power equal to the hydroelectric power lost by Canada as a result of operations to provide the additional storage. This arrangement is to continue for a period of 60 years after the date of ratification of the treaty (September, 1964). However, other provisions of the treaty require that this "on-call" storage shall not be requested unless flood forecasts predict a peak discharge in excess of 600,000 cfs at The Dalles, Oregon (regulated by all available storage in the U. S. and Canada).

The presentation in previous figures of the hydrographs for floods expected in a high flow year (1956) were based on computer studies in which it was assumed that a total of 7,000,000 acre-feet of storage would be available in Mica Reservoir at the start of the flood season. This means that about 5,000,000 acre-feet of this would have been part of the "on-call" storage. In the analysis of the average year flood (1952) it was assumed that "on-call" storage would not be required.

Although there is 10,000,000 acre-feet of storage available at Mica in addition to the 2,000,000 acre-feet required for flood control, not all of this should be considered a potential additional source for spill reduction during the critical periods of the flood runoff. First, winter power requirements usually result in Mica being drawn down to an extent such that more storage than the 2,000,000 acre-feet is available at the beginning of the flood season. For example, the "average year" hydrographs shown on Figure 10b(2) reflects the use of 5,760,000 acre-feet of storage space at Mica. Thus any special "on-call" space at Mica designated for spill reduction is likely to be considered less than the total 10,000,000 acre-feet. Second, due to minimum release restrictions at Grand Coulee there is a limit to which lower river flows can be reduced during the height of the flood runoff. Finally, if a special "on-call" system were implemented, this storage could not be made available in every large runoff year, statistically speaking, since not all large runoffs can be forecasted far enough in advance to get the Mica pool drawn down far enough to make the additional "on-call" storage available during the flood season.

It is very difficult to determine the actual effect on downstream flows of using or not using the "on-call" storage available in Canada. This is because of the irregular sequence of inflows, storage releases, and buildup of flows downstream. However, results of one study conducted by the Corps of Engineers, using the system as it would be regulated after 1975, and based on a relatively high runoff year (1951) do give an indication of the possible magnitude of the additional downstream regulation. In that study, downstream flows under an integrated system operation were calculated for two separate cases. In the first case, the storage available in the Canadian projects at the beginning of the flood season was approximately 7,000,000 acre-feet. In the second case, the "on-call" storage was utilized and approximately 14,000,000 acre-feet were assumed to be available in the Canadian projects prior to the flood season. The results showed essentially no difference in streamflow between the two cases until approximately May 15. During the end of May and the first part of July, the use of the additional "on-call" storage reduced streamflows at The Dalles by about 40,000 cfs. Interestingly, the greatest effect of the "on-call" storage occurred later in the year. In July, the use of the "on-call" storage was found to reduce the flow by some 100,000 - 150,000 cfs.

This use of "on-call" storage would be subject to the cost limitations cited previously. Also, the Columbia River Treaty would undoubtedly have to be amended. However, the fact that the additional storage could provide substantial extra control of downstream river flows suggests that it should be given further consideration and that additional studies should be directed to determine more precisely the actual level of downstream control which could be obtained, the true cost of the operation in a particular year, and the procedural difficulties which would be involved in revising the treaty and preparing flood control plans for its eventual use.

A last method of controlling spills which is physically possible but which may have serious operational, structural and possibly legal concerns operating against it, would be the provision of complete bypass capability. This measure would require that each dam in the system have some type of bypass facility which could, without entraining excess nitrogen, pass any flows in excess of flows which could safely be passed through turbine generator units, skeleton bays, and navigation locks. The capacity of this diversion facility could be based on a flood selected to have such a frequency (say, the once in ten year event) that recurrence of nitrogen problems that often would not result in undue damage to the fishery resource.

Effects of Future System Operation

As population and industry continue to expand and power requirements continue to increase, the systems used for generating power will grow and change. The following discussion of changes in the use of reservoir storage for power generation was developed by power planning agencies in the Pacific-Northwest (Anonymous, 1970):

> "The pattern of storage regulation for hydroelectric power production will change as the Pacific Northwest integrated power system progresses from a hydro base to a thermal base. During the initial stage all available power storage will be used during the adverse water years to produce the maximum possible prime power. This will establish the maximum firm load which can be carried by the system, and therefore, in years of better than minimum flow, the available storage will not be fully used for power generation. During the second stage of development, thermal generation will grow rapidly, and installations at main river hydro plants will be expanded. All available energy, including much that was formerly spilled, will become usable for replacing thermal electric energy. As much storage will be withdrawn during the winter season as can be replaced with forecasted flood season flows. As a result, the average annual use of storage will be greater than in the initial stage. During periods of adverse streamflow, all power storage necessary to meet firm loads will be used as it would be in the initial stage.
>
> "In the ultimate stage of development, reservoirs will [could] 1/ be maintained at a relatively high level to provide full plant peaking capability until the January peak load has occurred. Following the annual peak load, storage will be withdrawn, on a forecast basis, to generate hydro energy to replace thermal energy and to prevent subsequent spill during the flood runoff season. The change

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1/ Preferred wording by BPA

> from one stage to the next will be gradual, and the length of each period will depend on the rate of load growth, the rate of adding new storage and thermal generation, and the magnitude of the ultimate hydro-installed capability. The common objective in all three periods is to reduce the spill of water during the high runoff period by storing flows in excess of downstream plant hydraulic capabilities and thus convert potential spill into a usable commodity."

A major area of concern related not only to nitrogen supersaturation and the fishery resource but also to other water uses of the Columbia River system, such as recreation, navigation, and wildlife habitat, is the possible future effects of the increased use of hydro projects on the river for "power peaking." "Power peaking" is the term used to refer to power generation operations designed to meet the diurnal fluctuation in power demands. Figure 21 shows the fluctuation in load during the hours of a typical day in the Pacific Northwest. In the diagram and the discussions which follow, the firm load represents that portion of the demand for which firm contracts for power have been written between the power user (a municipality or industry) and the power marketing agency. The secondary load is additional load, usually industrial, for which there are no firm contracts but which could be served providing there is enough generating capability available. Municipal power use is the primary factor responsible for the wide variations in hourly loads, indistrial loads normally tend to be relatively stable during a daily cycle.

Table 3 shows projected future electric power requirements in the Columbia-North Pacific region. The "load factor" is the ratio of the average load during a period to the peak load occurring in that period and expressed as a percentage. It may be noted that although there is a 470 percent increase in average megawatts of demand from 1980 to 2020, the load factor through this same period remains relatively constant. Table 3 shows that in 1980 the peak power demand will be approximately 12,400 megawatts above the average load; in 2020 the need for peak power will be approximately 66,600 megawatts above the average power load.

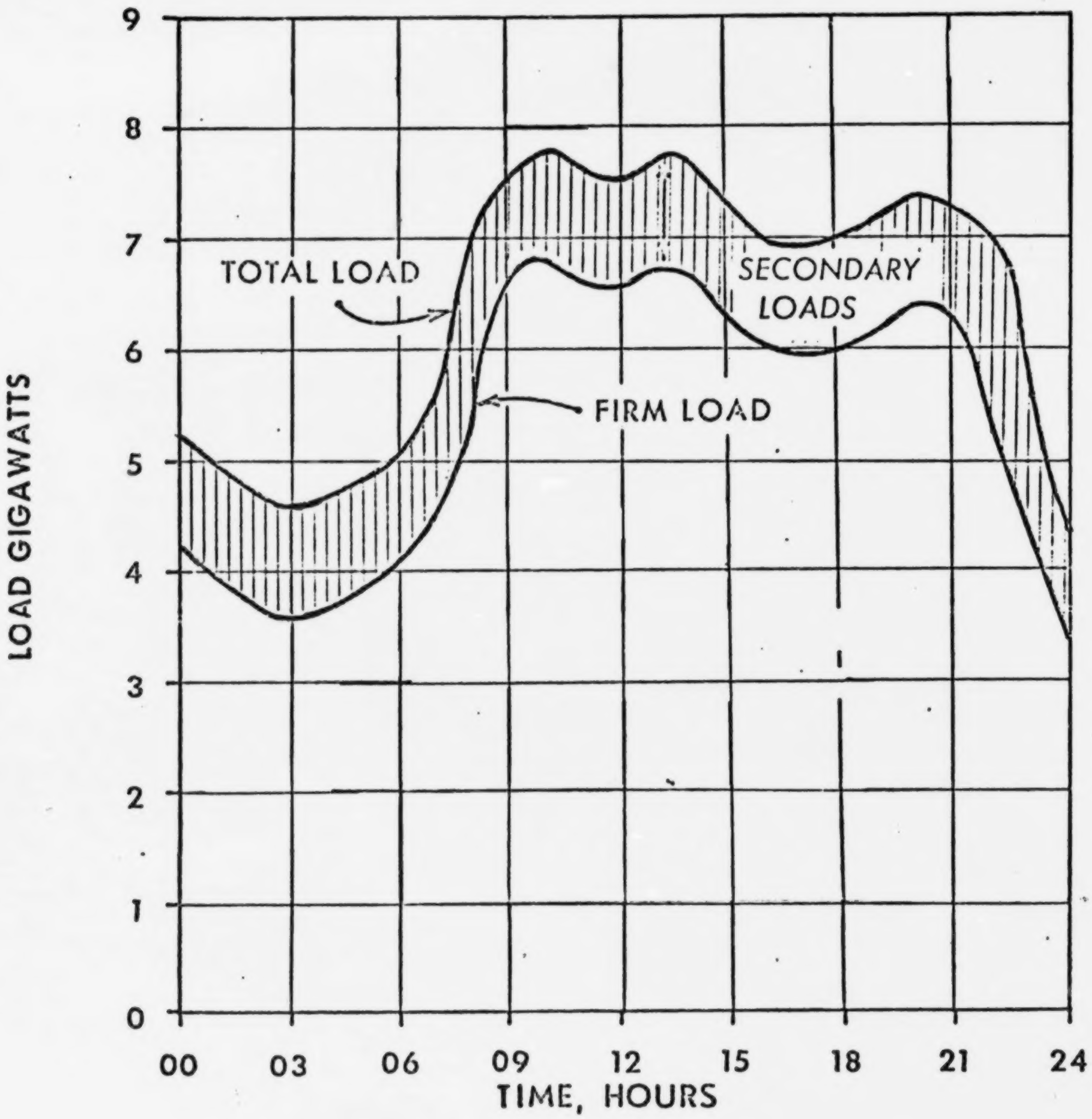

Figure 21 Daily Load Shape, Federal System 1/.

1/ Reference: Anonymous, 1971C

TABLE 3

Future Electric Power Requirements, Columbia -North Pacific Region [1]

	1965	1980	2000	2020
Population (millions)	5.9	7.3	9.7	12.7
Ratio: Pop./Dom. Cust.	3.1/1	2.8/1		
Domestic Customers	1,878,814	2,607,000		
KWH Use per Dom. Cust.	11,011	17,700		
Total Domestic Use GWH [2]	20,687	46,144		
Ratio: Pop./Com. Cust.	24.5/1	22.5/1		
Commercial Customers	239,883	325,000		
KWH Use per Com. Cust.	36,607	67,200		
Total Com. Cust. GWH	8,781	21,840		
Industrial Customers	6,486	---		
Industrial KWH Use per Capita	5,936	---		
Total Industrial Use GWH	34,346	99,000		
Irrigation GWH	2,421	6,593		
Other GWH	1,090	2,259		
Total Sales GWH	67,325	175,836		
Losses	7,110	17,364		
Total Requirements GWH	74,435	193,200	479,000	1,096,000
Per Capita KWH Requirements	12,676	26,500	49,400	86,300
Peak-megawatts	13,068	34,400	84,800	191,700
Average-Megawatts	8,497	22,000	54,660	125,060
Load Factor--Percent	65.0	64.0	64.4	65.0

Electric Power estimates for the region with alternate higher population projections in the Puget Sound and Willamette subregions would be as follows:

	2000	2020
Total Requirements Million KWH	512,000	1,286,000
Peak-Megawatts	91,300	229,400

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[1] Reference: Anonymous, 1970

[2] All kilowatt-hour data refers to annual use.

Hydroelectric plants at dams on the Columbia and Snake Rivers have the unique ability to start quickly and change power output rapidly. This makes them especially suitable for carrying peak loads and supplying spinning reserves. For this reason, present plans for power development in the Columbia-North Pacific region call for the expansion of hydroelectric generating facilities to be used to generate greater and greater portions of the peak power demands, and thereby operate at least lower load factors.

Both the Libby and Dworshak power plants have been designed to operate ultimately at an annual capacity factor (see Glossary) of approximately 20 percent. In other words, they will be able to generate peak power five times greater than the average load carried. At the Columbia River and lower Snake run-of-river projects, facilities are also being included in the initial phase of development for future installation of additional peaking units. However, in the interest of navigation and other water uses, the ultimate annual capacity factor of these plants has been limited to about 40 percent. The amount of base load which will be carried by these hydroelectric plants will thus decrease in the future, leaving thermal generating facilities to carry more and more of the base load, until eventually thermal generating facilities will be carrying nearly all the base load. Table 4 lists the projected thermal capacity which will be installed in future years and Table 5 is an installation schedule for generating units at hydro projects in the Pacific Northwest region. These tables are under continuous revision as power demand forecasts are revised through the years.

Because, generally, thermal plants are more expensive to operate than hydroelectric plants, the operating procedure for the future will be as follows: Firm load plus secondary energy loads will be generated by hydroelectric power resources until the full load is met--thermal power will be completely shut down if necessary to reduce spills. The foregoing statement applies mainly to seasonal or relatively long-term shifts in power generation. The statement must be tempered with the availability of loads, with the load factoring capability of hydroelectric plants, and with the cost of thermal replacement energy.

As the total system load increases, load factoring will increase at the hydro plants, with consequently increasing amounts of daily spills during the off-peak periods. This is one of the primary effects of power-peaking operations.

TABLE 4 INSTALLATION SCHEDULE FOR THERMAL PROJECTS 1/ and 5/

Plant		Type of Fuel	Rating 2/		Date Scheduled 3/		Sponsor 4/
No.	Name		Unit	Mw			
1	Centralia	Coal	1	700	Sept.	1971	PP&L Co. &
			2	700	Sept.	1972	WWP Co.
2	Trojan	Nuclear	1	1,106	Sept.	1974	PGE Co.
3	Jim Bridger	Coal	2	500	Sept.	1975	PP&L Co.
			3	500	Sept.	1976	PP&L Co.
4	Hanford #2	Nuclear		1,100	Sept.	1977	WPPSS
5	--	Thermal		1,100	Sept.	1978	Private
6	--	Thermal		1,100	Sept.	1979	Private
7	--	Thermal		1,100	Sept.	1980	Public
8	--	Thermal		1,100	Apr.	1982	Private
9	--	Thermal		1,100	Apr.	1983	Private
10	--	Thermal		1,200	July	1984	Public

1/ All information for plants 5 through 10 is tentative.

2/ Size of some units may vary from that forecast if a different type of fuel and/or location is selected. Plants 8 through 10 might be as large as 1,500 megawatts.

3/ Schedules may be rearranged between projects depending on needs of sponsoring utilities.

4/ Sponsors for plants 8 through 10 have been tentatively identified only as to type of utility according to present estimates of energy requirements

5/ Prepared by Bonneville Power Administration, Branch of Power Resources, December 29, 1970.

TABLE 5 INSTALLATION SCHEDULE FOR HYDRO PROJECTS 1/
(See footnotes on page 94)

Project 2/	Unit No.	Nameplate Megawatts 3/	Initial Date of Operation 4/	Status 5/
Rocky Reach Additions (Chelan Co. PUD)	8	125.4	July 1971	UC
	9	125.4	Sept. 1971	UC
	10	125.4	Oct. 1971	UC
	11	125.4	Nov. 1971	UC
John Day*	15	135	Aug. 1971	UC
	16	135	Oct. 1971	UC
	17, 18	135 ea.	Oct. 1988	F
	19, 20	135 ea.	Dec. 1988	F
The Dalles*	15	86	Aug. 1972	UC
	16	86	Nov. 1972	UC
	17	86	Feb. 1973	UC
	18	86	May 1973	UC
	19	86	Aug. 1973	UC
	20	86	Nov. 1973	UC
	21	86	Feb. 1974	UC
	22	86	May 1974	UC
Dworshak*	1	90	Nov. 1972	UC
	2	90	Feb. 1973	UC
	3	220	May 1973	UC
	4	220	Aug. 1985	F
	5	220	Oct. 1985	F
	6	220	Dec. 1985	F
Grand Coulee Pump Generators*	P/G-7	50	Apr. 1973	UC
	P/G-8	50	June 1973	UC
	P/G-9--P/G-12	50 ea.	Sept. 1989	F
3rd Powerplant*	G-19	600	Feb. 1974	UC
	G-20	600	Aug. 1974	UC
	G-21	600	Feb. 1975	UC
	G-22	600	Sept. 1979	UC
	G-23	600	Mar. 1980	UC
	G-24	600	Sept. 1980	UC
	G-25 6/	600	Sept. 1988	F
	G-26 6/	600	Mar. 1989	F
	G-27 6/	600	Sept. 1989	F
Libby*	1	105	Jul. 1975	UC
	2	105	Oct. 1975	UC
	3	105	Jan 1976	UC
	4	105	Apr. 1976	UC

TABLE 5 INSTALLATION SCHEDULE FOR HYDRO PROJECTS 1/
(Continued)

Project 2/	Unit No.	Nameplate Megawatts 3/	Initial Date of Operation 4/	Status 5/
Ice Harbor*	4	111	Feb. 1975	UC
	5	111	May 1975	UC
	6	111	Aug. 1975	UC
Lower Granite*	1	135	Apr. 1975	UC
	2	135	Apr. 1975	UC
	3	135	Apr. 1975	UC
	4	135	Feb. 1983	F
	5	135	May 1983	F
	6	135	Aug. 1983	F
Lost Creek*	1	24.5	Apr. 1976	UC
	2	24.5	June 1976	UC
Teton*	1	10	May 1976	UC
	2	10	June 1976	UC
	3	10	June 1978	F
Chief Joseph*	17	95	Nov. 1976	P
	18	95	Feb. 1977	P
	19	95	May 1977	P
	20	95	Aug. 1977	P
	21	95	Nov. 1977	P
	22	95	Jan. 1978	P
	23	95	Mar. 1978	P
	24	95	May 1978	P
	25	95	July 1978	P
	26	95	Sept. 1978	P
	27	95	Nov. 1978	P
Bonneville 2nd Powerplant*	11	54	Feb. 1978 7/	P
	12	54	May 1978	P
	13	54	Aug. 1978	P
	14	54	Nov. 1978	P
	15	54	Feb. 1979	P
	16	54	May 1979	P
Little Goose*	4	135	Feb. 1978	P
	5	135	May 1978	P
	6	135	Aug. 1978	P
Asotin*	1, 2	135 ea.	Apr. 1980	P
Guffey	1, 2, 3, 4	21.25 ea.	July 1981	F
Lower Scriver	1, 2	30 ea.	May 1982	F
	3, 4	30 ea.	July 1982	F

TABLE 5 INSTALLATION SCHEDULE FOR HYDRO PROJECTS 1/
(Continued)

1/ Includes projects under construction, authorized, recommended and proposed (potential).

2/ Ownership is Federal unless otherwise shown.

3/ Manufacturer's rating and does not necessarily represent maximum capability.

4/ Unit schedules for installation subsequent to 1980 are tentative and are subject to change depending on projected loads and plans of constructing entities.

5/ UC - Under construction
P - Planned for early installation
F - Future

6/ Authorization required for these units and for units G-28, 29, and 30.

7/ Based upon a site selection having a construction period of five years.

* Authorized for Federal Construction

Table 6 shows a load-resource analysis for the Columbia-North Pacific region, assuming maximum development of the hydro system. Under this plan, by the year 2000, essentially all of the hydroelectric resources will have been developed. The table also gives an indication of the magnitude of the maximum power-peaking that could be required from hydroelectric resources. For example, in the year 2020 the hydroelectric resources would carry 15,000 megawatts of the average energy load but would be peaked up to 56,000 megawatts to meet peak power demands, while at the same time the thermal resources would be held relatively constant. This could mean a huge amount of daily spilling as hydroelectric power-generating facilities are dropped off-line at night during the off-peak periods.

The basic assumption used in preparing Table 6 was that the future thermal plants would be designed to operate most efficiently on a continual basis. It is generally assumed that these plants would operate at an 85 percent plant factor (see GLOSSARY). The 15 percent reserve would allow for forced outages, maintenance, etc. Their full, rated capacity would be dependable for meeting critical period peaking requirements. It was also assumed that when sufficient water is available to the hydro-electric system, energy would be produced there for replacement of thermal power generation and the thermal plants would be shut down in order of decreasing energy cost (fuel costs). With no load factoring at the thermal plants, then, it can be seen that the hydroelectric generating plants have to be, in the future, varied greatly on a diurnal cycle. This would result in a diurnal cycle of spilling and no-spill during the high flow season (see Figure 22a).

Existing technology in thermal-electric generating facilities, however, indicates that thermal plants may be load factored to some extent. A limit on load factoring of thermal plants would probably be at a maximum rate of about 5 percent per minute. This amount of flexibility could significantly assist the effort to reduce diurnal spilling at hydroelectric projects during the high water season. If this capability is to be utilized, complex scheduling and coordination of fuel supply contracts, refueling operations, maintenance, and repairs will be required. Figure 22a shows pictorially the way in which the diurnal spills could fluctuate during the high flow season under a normal peaking operation in the future. Figure 22b shows the type of operation which could result with some load factoring at the thermal plants. Available pondage and storage are assumed used in the same fashion for both Figures 22a and 22b.

Table 6

Load Resource Analysis: Plan A [1], Columbia-North Pacific Region [11]

	OBERS [2] Population Estimates			Maximum Population Estimates [5]		
Item	1980[4]	2000	2020	1980[4]	2000	2020
Energy (Thousand Megawatts -- average)						
Load	18.2	54.7[5]	125.1[5]	18.2	58.4[5]	146.8[5]
Reserves	0.5[6]	6.9[7]	19.3[7]	0.5[6]	3.2[7]	23.1[7]
Total Load	18.7	61.6	144.4	18.7	61.6	169.9
Hydro Resources	11.9	15.5	15.5	11.9	15.5	15.5
Thermal Resources	6.3	38.1	116.9	6.3	38.5	142.4
Thermal Imports	0.5	8.0	12.0	0.5	8.0	12.0
Total Resources	18.7	61.6	144.4	18.7	62.0	169.9
Peaking Capability (Thousand Megawatts)						
Load	30.0	84.8[5]	191.7[5]	30.0	91.3[5]	229.4[5]
Reserves [8]	3.8	10.2	23.1	3.8	11.0	27.5
Total Load	33.8	95.0	214.8	33.8	102.3	256.9
Hydro Resources	26.3	56.0	56.0	26.3	56.0	56.0
Base Load Thermal	7.3	38.1	116.7	7.3	38.5	142.4
Thermal Imports	0.2	8.0	12.0	0.2	8.0	12.0
Peaking Resources [9]	0.0	0.0	30.1	0.0	0.0	46.5
Total Resources	33.8	102.1[10]	214.8	33.8	102.5[10]	256.9

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[1] Maximum hydro system.

[2] Based on Columbia-North Pacific population forecasts prepared by OBE-ERS.

[3] Same population forecasts as above for 10 of the 12 subregions; population forecasts for Subregions 9 and 11 from the respective Type 2 studies.

[4] Data derived from Pacific Northwest Utility Conference Committee West Group Forecast Estimates.

[5] From table 22 (Anonymous, 1970)

[6] Energy reserves for 1980 based on one-half year's utility load growth.

[7] Fifteen percent of the required thermal capability (including imported thermal).

[8] Based on 12 percent of load. Reserves for 1980 computed using Pacific Northwest Coordination Agreement probability analysis formula.

[9] Pumped storage, gas turbines, or other peaking resources.

[10] Surplus capability resulting from import of thermal energy.

[11] Reference: Anonymous, 1970.

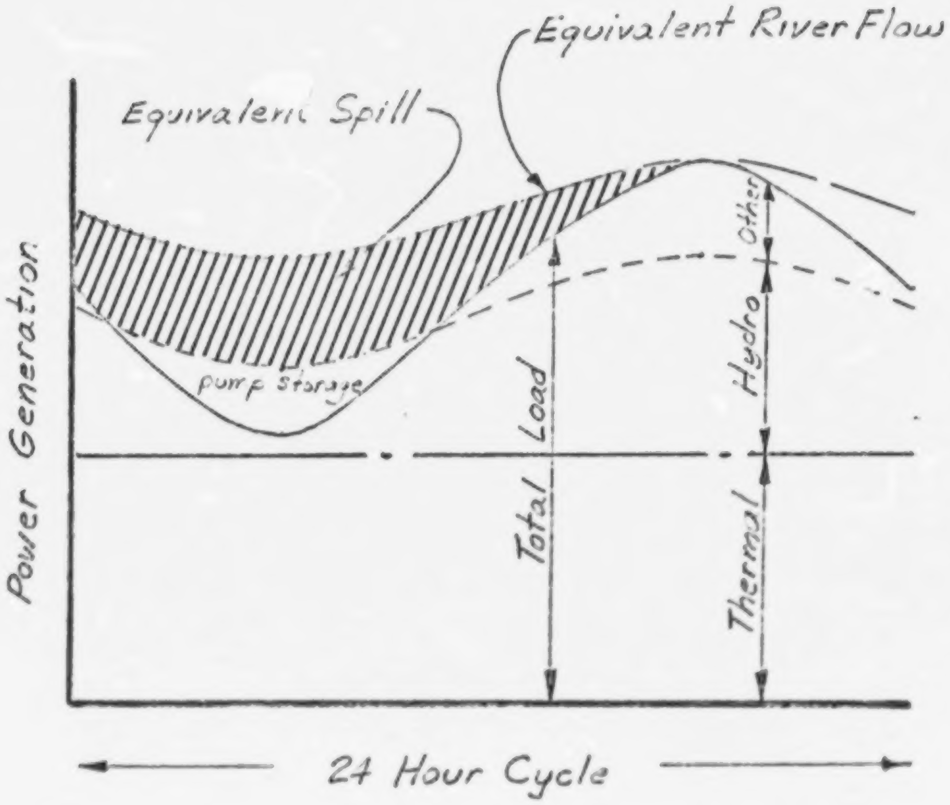
Equivalent River Flow
Equivalent Spill
Power Generation
pump storage
Total Load
Other
Hydro
Thermal
24 Hour Cycle

Figure 22a. Load Factoring at Hydro Plants Only

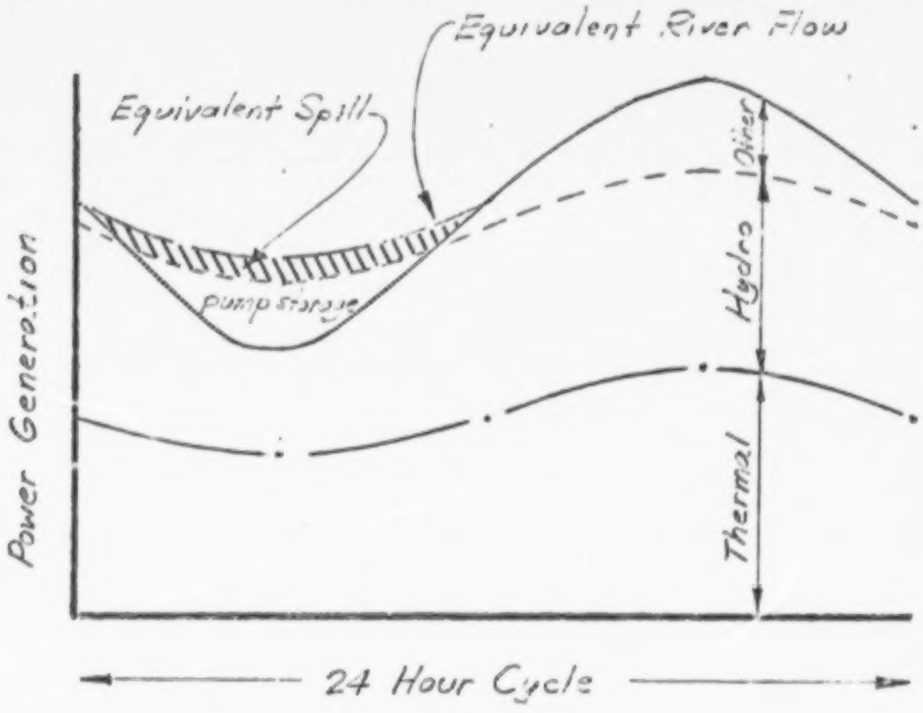
Equivalent River Flow
Equivalent Spill
Power Generation
pump storage
Other
Hydro
Thermal
24 Hour Cycle

Figure 22b. Load Factoring at Thermal Plants and Hydro Plants

Proposed pump-storage operations (see discussion of pumped storage in the APPENDIX) at many hydro projects offers another possibility for reducing daily spills. At the presently projected rate of power development, supplemental peaking capacity beyond that available by development of conventional hydro-projects will probably not be required until after 1990. Studies are now being conducted to determine when and how pumped storage will best fit into the regional load projections. It is evident that pumped storage offers considerable promise as a source of future peaking capacity and spill reduction.

The above comments have all been based on load and power generation forecasts on a region-wide basis. At this time, there are no detailed studies available which indicate the character of seasonal and diurnal spills in future years. However, computer programs and basic data are available to perform this type of analysis and these studies should be conducted in the near future. Objectives of such a study should be to determine how much spilling may occur in the future, the detailed effects of power peaking and pumped storage, and the feasibility of using load factoring at the thermal plants to help reduce seasonal and diurnal spilling at the hydroelectric projects.

Needs for Further Study

Throughout the report, gaps in data and needs for additional study have been mentioned as each topic was discussed. The following listing summarizes the needs for additional work related to engineering aspects of the nitrogen problem.

1. Detailed computer studies should be oriented toward predicting levels of spills in future years and under variations in the system operation discussed in this chapter.

2. Studies of estimated costs of the many alternatives for controlling nitrogen should be made to provide bases for decisions on implementation.

3. Studies on turbine-generator design should be continued toward development of units which can pass large quantities of water at low load without damaging effects to fish or structures.

4. Additional studies should be performed to develop non air-entraining spillway stilling basin designs.

5. An inventory of bypass capability at each dam on the Columbia and Snake Rivers should be made.

6. The potential effects of Canadian Treaty Storage should be investigated further.

7. Methods of reducing the detrimental effects of power peaking should be studied further. These methods include load factoring at proposed thermal plants and operation of future pump-storage projects.

8. Better correlations between spillway flows and nitrogen levels are needed.

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GLOSSARY [1]

AVERAGE MEGAWATT - A unit of average energy output over a specified time period (total energy in megawatt-hours divided by the number of hours in the time period).

BASE LOAD - See Load, Base.

BRITISH THERMAL UNIT (Btu) - The standard unit for measurement of the amount of heat energy, such as the heat content of fuel. Equal to the amount of heat energy necessary to raise the temperature of one pound of water one degree Fahrenheit.

CAPABILITY - The maximum load which a generator, turbine, power plant, transmission circuit, or power system can supply under specified conditions for a given time interval without exceeding approved limits of temperature and stress.

Maximum Plant Capability (Hydro) The maximum load which a hydroelectric plant can supply under optimum head and flow conditions without exceeding approved limits of temperature and stress. This may be less than the overload rating of the generators due to encroachment of tailwater on head at high discharges.

Peaking Capability - The maximum peak load that can be supplied by a generating unit, station, or system in a stated time period. For a hydro project the peaking capability would be equal to the maximum plant capability only under favorable pool and flow conditions, often the peaking capability may be less due to reservoir drawdown or tailwater encroachment.

Ultimate Plant Capability (Hydro) - The maximum plant capability of a hydroelectric plant when all contemplated generating units have been installed.

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[1] Reference: Anonymous, 1970

CAPACITY - The load for which a generator, transmission circuit, power plant, or system is rated. Capacity is also used synonymously with capability.

Dependable Capacity - The load-carrying ability of a station or system under adverse conditions for the time interval and period specified when related to the characteristics of the load to be supplied. For hydro projects the term refers to the capability in the most adverse month in the critical period--January 1932 in the case of the 1928-32 critical period.

Firm Capacity - Capacity which has assured availability to the customer on a demand basis. System firm capacity consists essentially of hydro system dependable capacity plus thermal plant installed capacity plus firm imports minus maintenance and forced outage reserves.

Hydraulic Capacity - The maximum flow which a hydroelectric plant can utilize for power generation.

Installed Capacity - Same as nameplate capacity unless otherwise specified.

Nameplate Capacity - The nominal rated capacity of a generating unit or other similar apparatus. The term gives an indication of the approximate generating capability of the unit, but in many cases the unit is capable of generating on a continuous basis substantially more than the nameplate capacity (see Overload Capacity, below).

Overload Capacity - The maximum load that a machine, apparatus, or device can carry for a specified period of time under specified conditions when operating beyond its nameplate rating but within the limits of the manufacturer's guarantee or, in the case of expiration of the guarantee, within safe limits as determined by the owner. For example, most of the generators installed in the region's newer hydroelectric plants have a continuous overload capacity of 115 percent of the nameplate capacity.

Peaking Capacity - Same as Peaking Capability.

Reserve Capacity - Extra generating capacity available to meet unanticipated demands for power or to generate power in the event of loss of generation resulting from scheduled or unscheduled outages of regularly used generating capacity.

CAPACITY FACTOR - The ratio of the average load on the generating plant for the period of time considered to the capacity rating of the plant. Unless otherwise identified, capacity factor is computed on an annual basis. In this Appendix, the capacity factor of a hydro plant is based on maximum plant capability and assumed load equal to the average annual energy.

CONVENTIONAL HYDROELECTRIC PLANT - A hydroelectric power plant which utilizes streamflow only once as it passes downstream, as opposed to a pumped-storage plant which recirculates all or a portion of the streamflow in the production of power.

COORDINATED COLUMBIA RIVER SYSTEM - Contractually, the system of hydroelectric projects located on the Columbia River and major tributaries which are operated together on a coordinated basis under the terms of the Pacific Northwest Coordination Agreement. The term is sometimes used in a more general sense to include also those projects which are operated by utilities not participating in the Coordination Agreement.

COORDINATION AGREEMENT - See pages 31-34.

CRITICAL PERIOD - Period when the limitations of hydroelectric power supply due to water conditions are most critical with respect to system energy requirements. For a discussion of the critical period as it applies to the regional hydroelectric system, refer to page 135.

CRITICAL WATER YEAR - A term sometimes used interchangeably with Critical Period when the critical period falls within one operating year. The term will lose all significance when the system moves into a multi-year critical period (see page 136).

DEMAND - The rate at which electric energy is delivered to or by a system at a given instant or averaged over any designated period of time, expressed in kilowatts or other suitable units.

DRAWDOWN - The distance that the water surface of a reservoir is lowered from a given elevation as the result of the withdrawal of water. In specific cases in this Appendix, drawdown may refer to the maximum drawdown for power operation, from normal full pool to minimum power pool. Sometimes drawdown is also expressed in terms of acre-feet of storage withdrawn.

ELECTRO-PROCESS INDUSTRY - An industry which requires very large amounts of electricity in manufacturing for heat or chemical processes (as distinguished from wheel-turning or mechanical applications). Examples are electric furnace steel, aluminum, and chlorine.

ENERGY - That which does or is capable of doing work. It is measured in terms of the work it is capable of doing; electric energy is commonly measured in kilowatt-hours or average megawatts.

Average Annual Energy - Average annual energy generated by a hydroelectric project or system over a specified period. In the Pacific Northwest the average output of most projects is based on the historical flows experienced during the period 1928-58, as modified by appropriate irrigation depletions.

Firm Energy - Electric energy which is considered to have assured availability to the customer to meet all or any agreed upon portion of his load requirements. Firm energy is based on certain specified probability considerations, which, in the Pacific Northwest, are related to the 1928-58 sequence of historical streamflows adopted for making system power regulations. System firm energy capability includes hydro system prime energy, thermal plant energy capabilities, and firm imports.

Prime Energy - Hydroelectric energy which is assumed to be available 100 percent of the time: specifically, the average energy generated during the critical period.

Secondary Energy - All hydroelectric energy other than prime energy: specifically, the difference between average annual energy and prime energy.

Usable Energy - All hydroelectric energy which can be used in meeting system firm and secondary loads. In the early years of this study, it is possible that there may not be a market for all of the secondary energy which could be generated in years of abundant water supply and some of the water may have to be diverted over project spillways and the energy wasted.

ENERGY DEMAND - See Demand.

FIRM - Assured.

FIRM LOAD CARRYING CAPABILITY (FLCC) - The firm load that a system could carry under coordinated operation under critical period streamflow conditions with the use of all reservoir storage (refer to page 33). More specific terms are Firm Energy Load Carrying Capability (FELCC) and Firm Peak Load Carrying Capability (FPLCC). The general term refers collectively to both.

FOREBAY - The impoundment immediately above a dam or hydroelectric plant intake structure.

GENERATION - The act or process of producing electric energy from other forms of energy; also the amount of electric energy so produced.

GIGAWATT - One million kilowatts, or one billion watts.

HEAD

Gross Head - The difference of elevations between water surfaces of the forebay and tailrace under specified conditions. In this Appendix, gross head generally refers to the difference between normal full pool and average tailwater.

Net Head (Effective Head) - The gross head less all hydraulic losses except those chargeable to the turbine.

HEAT RATE - A measure of generating station thermal efficiency, generally expressed as Btu per (net) kilowatt-hour. It is computed by dividing the total Btu content of the fuel burned (or of heat released from a nuclear reactor) by the resulting net kilowatt-hours generated.

HYDRAULIC CAPACITY - See Capacity, Hydraulic.

INDEPENDENT RESOURCES (HYDROELECTRIC) - The hydroelectric projects of the region which are not included in the Coordinated Columbia River System (see page 135).

IMPORTS - Power imported from outside the Columbia-North Pacific Region system being considered, in this Appendix.

INTERTIE - See Transmission Interconnection.

KILOWATT (kw) - The electrical unit of power which equals 1,000 watts or 1.341 horsepower.

KILOWATT-HOUR (kwh) - The basic unit of electrical energy. It equals one kilowatt of power applied for one hour.

LOAD - The amount of power delivered to a given point.

Base Load - The minimum load in a stated period of time.

Firm Load - That part of the system load which must be met with firm power.

Peak Load - Literally, the maximum load in a stated period of time. Sometimes the term is used in a general sense to describe that portion of the load above the base load.

LOAD FACTOR - The ratio of the average load over a designated period to the peak load occurring in that period. In this Appendix the term applies to annual load factor unless otherwise specified.

LOAD SHAPE (LOAD PATTERN) - The characteristic variation in the magnitude of the power load with respect to time. This can be for a daily, weekly, or annual period.

LOSSES (ELECTRIC SYSTEM) - Total electric energy loss in the electric system. It consists of transmission, transformation, and distribution losses and unaccounted-for energy losses between sources of supply and points of delivery.

MEGAWATT (mw) - One thousand kilowatts, or one million watts.

MEGAWATT-HOUR (mwh) - One thousand kilowatt-hours, or one million watt-hours.

NORMAL FULL POOL - The maximum forebay water surface elevation within the reservoir's normal operating range.

NORTHWEST POWER POOL - See page 27.

PACIFIC NORTHWEST COORDINATION AGREEMENT - See pages 31-34.

PEAK LOAD - See Load, Peak.

PEAKING - Power plant operation to meet the variable portion of the daily load. See Load, Peak.

PEAKING PLANT - A power plant which is normally operated to provide all or most of its generation during maximum load periods.

PENSTOCK - A conduit to carry water to the turbines of a hydroelectric plant (usually refers only to conduits which are under pressure).

PLANT FACTOR - Same as Capacity Factor.

PONDAGE - Reservoir power storage capacity of limited magnitude that provides only daily or weekly regulation of streamflow.

POWER - The time rate of transferring energy. Note--The term is frequently used in a broad sense, as a commodity of capacity and energy, having only general association with classic or scientific meaning.

Firm Power - Power which is considered to have assured availability to the customer to meet all or any agreed upon portion of his load requirements. It is firm energy supported by sufficient capacity to fit the load pattern. The availability of firm power is based on the same probability considerations as is firm energy.

Interruptible Power - Nonfirm power; power made available under agreements which permit curtailment or cessation of delivery by the supplier. In the Pacific Northwest, interruptible power loads are met with secondary hydro energy.

Prime Power - Prime energy shaped to fit the regional load pattern.

Secondary Power - Same as Secondary Energy.

POWER DEMAND - See Demand.

PUMPED STORAGE PLANT - A hydroelectric power plant which generates electric energy for peak load use by utilizing water pumped into a storage reservoir during off-peak periods. Refer also to pages 85-87.

REGULATION (Hydroelectric System) - See pages 134-135.

RESERVES

Reserve Generating Capacity - See Capacity, Reserve.

Spinning Reserve - Generating capacity connected to the bus and ready to take load. It also includes capacity available in generating units which are operating at less than their capability.

RUN-OF-RIVER PLANT - A hydroelectric plant which depends chiefly on the flow of a stream as it occurs for generation, as opposed to a storage project, which has sufficient storage capacity to carry water from one season to another. Some run-of-river projects have a limited storage capacity (pondage) which permits them to regulate streamflow on a daily or weekly basis.

STORAGE

Dead Storage - The volume of water remaining in a reservoir after all of the usable storage has been withdrawn.

Gross (Total)- The total volume of water in a reservoir at normal full pool.

Seasonal Storage - Water held over from the annual high-water season to the following low-water season.

Usable Storage - The volume of storage in a reservoir which can be withdrawn for various conservation purposes (gross storage minus dead storage). As used in this Appendix the term refers to storage which can be withdrawn either jointly or exclusively for power generation.

STORAGE PROJECT - A project with a reservoir of sufficient size to carryover from the high-flow season to the low-flow season and thus to develop a firm flow substantially more than the minimum natural flow. A storage project may have its own power plant or may be used only for increasing generation at downstream plants.

TAILWATER - The water surface immediately downstream from a dam or hydroelectric powerplant.

THERMAL PLANT - A power generating plant which uses heat to produce energy. Such plants may burn fossil fuels or use nuclear energy to produce the necessary thermal energy.

TRANSMISSION GRID - An interconnected system of electric transmission lines and associated equipment for the movement or transfer of electric energy in bulk between points of supply and points of demand.

TRANSMISSION INTERCONNECTION (INTERTIE) - Transmission circuit used to tie or interconnect two load areas or two utility systems.

ULTIMATE DEVELOPMENT - The maximum contemplated generating installation at a power plant.

The following references were used in the preparation of the glossary.

1. Columbia-North Pacific Technical Staff, Glossary: Columbia-North Pacific Framework Study (Publication C-NP 11), December 1967, Vancouver, Washington
2. Federal Power Commission, Glossary of Important Power and Rate Terms, Abbreviations, and Units of Measurement (Prepared under the direction of the Inter-Agency Committee on Water Resources and promulgated by the Federal Power Commission). 1965, Washington, D. C.
3. Northwest Power Pool, Glossary of Terms Used in Coordinated Operation, January 1959, Portland, Oregon
4. Pacific Northwest Coordination Agreement, Agreement for Coordination of Operations Among Power Systems of the Pacific Northwest, September 1964, Portland, Oregon

The largest share of the definitions were drawn from the Federal Power Commission glossary, but in a number of cases these definitions had to be modified or supplemented to reflect regional usage of the terms.

APPENDIX [1/]

Pumped Storage

"Electrical resource studies indicate that, in the future, a major part of the Pacific Northwest's base load will be met by nuclear powerplants. Nuclear plants can supply base load energy at a relatively low cost, but are an expensive source of peaking power. Therefore, more economical means for providing peaking power must be sought. Studies indicate that the peaking requirements of the region will be met until about 1990, by adding generating units at existing conventional hydroelectric projects. When addition of those units is completed, other sources of peaking power must be developed. Several alternative sources are available, including pumped-storage. Recent improvements in reversible pump-turbines have created considerable interest in pumped storage, especially in areas where reservoir sites with high head are available, as they are in the Columbia-North Pacific Region.

Operation

"Pumped-storage hydro is unique among methods of power generation as it is dependent on other electrical power sources for its energy supply. It functions as an energy accumulator in that low-valued off-peak energy is stored by pumping water from a lower to a higher reservoir (figure 7) [figure 7 not in this report] . The stored water can then be returned through the turbines to generate power during peak load periods, when it is most needed and has its greatest value. Pumped-storage installations offer many of the favorable characteristics of conventional hydroelectric plants including rapid start-up, long life, dependability, low operating and maintenance costs, and adaptability as low cost spinning reserve. Due to transmission losses and inefficiencies in the operation of pumped-turbines, approximately one and one-half times as much energy is required for pumping as is obtained in the generating phase. However, this increased energy use is justified by the high value of the peak generation.

[1/] Quoted from (Anonymous, 1970)

"Pumped-storage may be designed to operate on a seasonal, weekly, or a daily cycle. Seasonal pumped-storage would be economical only in a system where there is a period in the year in which there is both surplus water and surplus energy. The surplus energy would be used to pump the surplus water into a holding reservoir to be used for generation during periods of greatest power demand. Projects of this type are especially adaptable to multi-purpose development. An example of this is the Paterson Ridge site, which is being considered as a multiple-purpose project for irrigation, recreation, thermal plant siting, and seasonal pumped-storage power generation.

"Daily and weekly pumped-storage hold considerable promise, especially in light of the fact that in the near future thermal plants will begin assuming an increasing share of the region's base load. As more thermal plants are put into operation, more off-peak energy will become available for potential use by pumped-storage plants. Water would generally be pumped at night (and on weekends) and released during the day to generate energy for meeting the system's peak loads.

"Pumped-storage projects are generally classified as either "pure" pumped-storage or "combined" pumped-storage. A "pure" pumped-storage project is one which operates exclusively as a pumped-storage plant. The plant's generation capability is dependent wholly on water pumped from the lower to the upper reservoir. On the other hand, a "combined" pumped-storage project is a conventional hydro project whose generating plant consists either partially or wholly of reversible pump-turbines. Water pumped from the lower pool serves only to supplement conventional reservoir inflow as a source of energy.

Summary

"It appears . . . that there is considerable pumped storage potential in the Columbia-North Pacific Region. In western Oregon and Washington alone there are nearly 300 sites worthy of consideration for development as 1,000 megawatt daily/weekly cycle peaking plants. Some of these sites possibly could be developed up to 10,000 megawatts. . . . indications are that there are also a few seasonal pumped-storage sites available and a number of convential hydro projects (existing as well as proposed) which could be developed as combined pumped-storage plants.

"At the presently projected rate of power development, supplemental peaking capacity beyond that available for development at conventional hydro projects will probably not be required until after 1990. However, as thermal plants are developed, the inexpensive off-peak energy which will be available may encourage the early development of some pumped-storage before 1990. An indication of the current interest in this is the fact that reversible units are now being installed at an existing project and that detailed studies are now underway on at least five additional pumped-storage sites. Furthermore, studies may show that pumped-storage would be more economical than some of the conventional hydro units currently scheduled to carry the additional peaking loads developing prior to 1990. For example, it may be found that it would be more economical to utilize the limited storage in The Dalles pool for pumped-storage operation rather than for handling the releases from the proposed John Day units #17-20.

"Studies are now being conducted to determine when and how pumped storage will best fit into the regional load curve. These studies should also give an indication as to the type and number of plants which will be required by the years 2000 and 2020. More studies will be required to determine the relative desirability of individual sites and the effects that the operation of these plants will have on their environment, but it is evident that pumped-storage offers considerable promise as a source of future peaking capacity."